U.S. DEPARTMENT OF COMMERCE PB80-168867

The Long-Term Effects of Trace Elements Emitted by Energy Conversion of Lignite Coal. Volume I

North Dakota State Dept. of Health
Bismark

Prepared for

Old West Regional Commission
Billings, MT

Jul 79

U.S. Department of Commerce
National Technical Information Service
NTIS

PB80-164467

THE LONG-TERM EFFECTS OF TRACE ELEMENTS EMITTED BY ENERGY CONVERSION OF LIGNITE COAL

Volume I

Prepared For

OLD WEST REGIONAL COMMISSION

July 1979

NORTH DAKOTA STATE DEPARTMENT OF HEALTH

Division of Environmental Research

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BIBLIOGRAPHIC INFORMATION

PB80-168867

The Long-Term Effects of Trace Elements Emitted by Energy Conversion of Lignite Coal. Volume I.

Jul 79

Martin R. Schock, William W. Morrison, and Gene A Christianson.

PERFORMER: North Dakota State Dept. of Health, Bismark.
Div. of Environmental Research.
Contract OWRC-10773210

SPONSOR: Old West Regional Commission, Billings, MT.
Final rept.

See also Volume 2, PB80-168875.

A two-year project, concerning effects of selected elements upon the ecosystem surrounding a 675-megawatt coal-fired electrical generating facility, was completed. This project involved the collection of coal, stack fly ash, aerosol, surface water, snow, sediments, soil, and vegetation samples for analysis of element concentrations. A modified atmospheric transport and deposition computer model was developed and used to predict ground-level air concentrations and development of elements from the burning of lignite coal. The results of the project provide evidence of enrichment of certain elements in aerosols, snow, water, soil surface, and vegetation.

KEYWORDS: *Environmental surveys, *Trace elements, *Coal fired power plants, *Air pollution sampling.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A12/MF A01

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PREPARED FOR
OLD WEST REGIONAL COMMISSION

JULY 1979

PREPARED BY

NORTH DAKOTA STATE DEPARTMENT OF HEALTH
DIVISION OF ENVIRONMENTAL RESEARCH

THE LONG-TERM EFFECTS OF TRACE ELEMENTS EMITTED BY ENERGY CONVERSION OF LIGNITE COAL

A Final Report Prepared For

OLD WEST REGIONAL COMMISSION
Billings, Montana
Grant Number 10773210

By

Martin R. Schock, William W. Morrison
and Gene A. Christianson

July 1979

NORTH DAKOTA STATE DEPARTMENT OF HEALTH
Division of Environmental Research
Bismarck, North Dakota

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ABSTRACT

A two-year project, concerning effects of selected elements upon the ecosystem surrounding a 675-megawatt coal-fired electrical generating facility, was completed. This project involved the collection of coal, stack fly ash, aerosol, surface water, snow, sediments, soil, and vegetation samples for analysis of element concentrations.

A modified atmospheric transport and deposition computer model was developed and used to predict ground-level air concentrations and development of elements from the burning of lignite coal. The aerosol, surface water, snow, sediment, soil, and vegetation samples were collected from a grid of field plots and samplers which emphasized certain directions and distances from the facility where maximum effects were anticipated.

The results of the project provide evidence of enrichment of certain elements in aerosols, snow, water, soil surface, and vegetation. However, the data indicate that the operation of Unit I at 235 megawatts for 10 years did not enrich aerosol, snow, soil, and vegetation concentrations of elements to toxic levels.

The effects on an ecosystem by the long term operation of a coal-fired facility over 40 years is expected to be insignificant. The long-term operation of several facilities in close proximity remains uncertain. It is recommended that additional field sampling occur at scheduled three-year intervals to monitor levels of element concentrations in certain vegetation species and in the surface layer of soil within the project study area.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the generous assistance of many persons in the form of methodology review, sample collection, and data interpretation. These persons are:

Dr. William Barker	Botany Department North Dakota State University
Dr. Mary Bromel	Bacteriology Department North Dakota State University
Dr. Thomas A. Cahill	Crocker Nuclear Laboratory University of California, Davis
Dr. Earle Cary	U.S Plant, Soil, & Nutrition Laboratory Agricultural Research Service
Dr. John Cooper	Department of Environmental Technology Oregon Graduate Center
Dr. James Erdman	U.S. Geological Survey - Denver
Mr. Dave Gouveia	Square Butte Power Cooperative
Dr. Gerald Groenewold	North Dakota Geological Survey
Ms. Mildred Johnson	State Library
Mr. Vern Laning	Basin Electric Power Cooperative
Mr. Marvin Leer	United Power Association
Mr. Steve Mercil	Biology Department University of North Dakota
Dr. John Moraghan	Soils Department North Dakota State University
Dr. Bruce Murry	Chemistry Department Wisconsin State University
Mr. Jim Nelson	Computer Center North Dakota State University
Dr. Michael J. Pilat	Department of Civil Engineering University of Washington

Mr. Fred Sandoval	Agricultural Research Service - Mandan
Dr. Ali Shaikh	Chemistry Department North Dakota State University
Dr. L. Elliott Schubert	Biology Department University of North Dakota
Dr. Rodney Skogerboe	Chemistry Department Colorado State University
Dr. P. N. Soltanpour	Soils Testing Laboratory Colorado State University
Dr. Dennis Tallman	Chemistry Department North Dakota State University
Mr. Ronald Timpe	Chemistry Department Mayville State College
Mr. John Wirtz	Montana-Dakota Utilities, Co.
Mr. Steve Workman	Soils Testing Laboratory Colorado State University

The assistance of the following staff of the North Dakota State Department of Health is also gratefully acknowledged:

Miss Mary Boelter	secretary-word processing
Miss Jalane Erhardt	aerosol sampler operator (subcontracted employee)
Mr. Ken Kary	director of laboratory facilities
Mr. Kevin Kiemele	stack sampling engineer
Ms. Cherie Kindsvogel	secretary-card punch operator
Mr. Timothy Link	field sampling technician
Mr. Terry O'Clair	stack sampling technician
Mr. Jim McWilliams	field sampling technician (subcontracted employee)
Mr. Rodney Reetz	laboratory sampling and sample preparation
Ms. Londa Rodahl	secretary-word processing
Mr. Paul Weiser	soil classifier (subcontracted employee)

The processing of data was achieved on an IBM 370-158 computer operated by the North Dakota State Central Data Processing Division. The authors appreciate the assistance of its staff, particularly Mr. George Bales.

We are particularly indebted to Dr. Rodney Skogerboe who performed the chemical analysis of the snow samples without charge to this project. We are also appreciative for the chromium analysis of selected vegetation samples performed independently by Dr. James Erdman and Dr. Earl Cary at no cost to this project.

The additional four weeks of water sampling during April 1979, were funded by the Field Research Unit, U.S. Fish and Wildlife Service, Yankton, South Dakota. We are grateful for the interest in the aquatics portion of this project by Mr. Dan Martin.

The principle investigator for the first fourteen months of this project was Mr. James K. Miller. Mr. Miller was responsible for supervising the field sampling and laboratory activities for the project. He subsequently terminated his employment with the Department to accept another position.

FORWARD

Appendices A, B, C, and D provide detailed discussions of sampling methods, laboratory techniques for analyses of element concentrations, computer model description and listing, and listings of all raw data used in this report. Due to the bulky nature of these appendices, they have been printed under a seperate cover. The appendices are available upon request.

The terminology used in this report, upon which conclusions are based, has been developed on two pairs of key words: suggest and indicate, more and less or increase and decrease. The word suggest is used when data and other evidence are insufficient to identify a significant conclusion: the word indicate is used when a significant conclusion can be stated. The words increase or decrease are used in statistical comparisons which provide significant differences: more or less are used when data differences are not statistically significant.

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1. INTRODUCTION

1.1 Background

The evolution of the crustal surface of planet Earth over millions of years was a dynamic mechanism for controlling all forms of life. For example, the Rocky Mountains of the Western United States were not the majestic features during most of the ages of Earth. Prior to the upheaval of Earth's crust creating the mountain ranges in the western United States, climatic conditions were more tropical in character permitting lush vegetation and animal life. While wind and rain contributed to a redistribution of elements within the soil, the major factors determining the crustal character were the decay of the plant and animal life causing the rich coal, oil, and gas resources followed by volcanic activity with wind distributing volcanic ash eastward across areas now known as Northern and Central Plains.

The conversion of coal energy contained in the vast coal reserves to electrical energy produces wastes which are continuing nature's redistribution of crustal elements. An increasing awareness of the potential environmental enrichment during the last decade has occurred among the political, industrial, and public sectors of society.

Coal contains chemical elements in varying concentrations. Trace elements can generally be defined as those minerals present within the ecosystem in concentrations of 1,000 parts per million (ppm) or less. This project is directed toward the study of the redistribution of certain elements within the waste products of coal-fired energy conversion facilities and the potential impacts on living organisms.

Waste products from a coal-fired energy conversion facility include air stream effluents from stacks, waste water discharge, bottom ash from precipitators and sludge from wet scrubbers. The principle elements which are evaluated during this project included arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), and zinc (Zn). Data for additional elements is also presented in this report.

The focus upon elements as potentially hazardous environmental contaminants has become an issue of increasing concern to the Nation and the States of the Old West Region. In 1975, the North Dakota State Department of Health initiated an investigation of the nature of enrichment of elements and potential environmental effects resulting from utilization of the region's coal reserves.

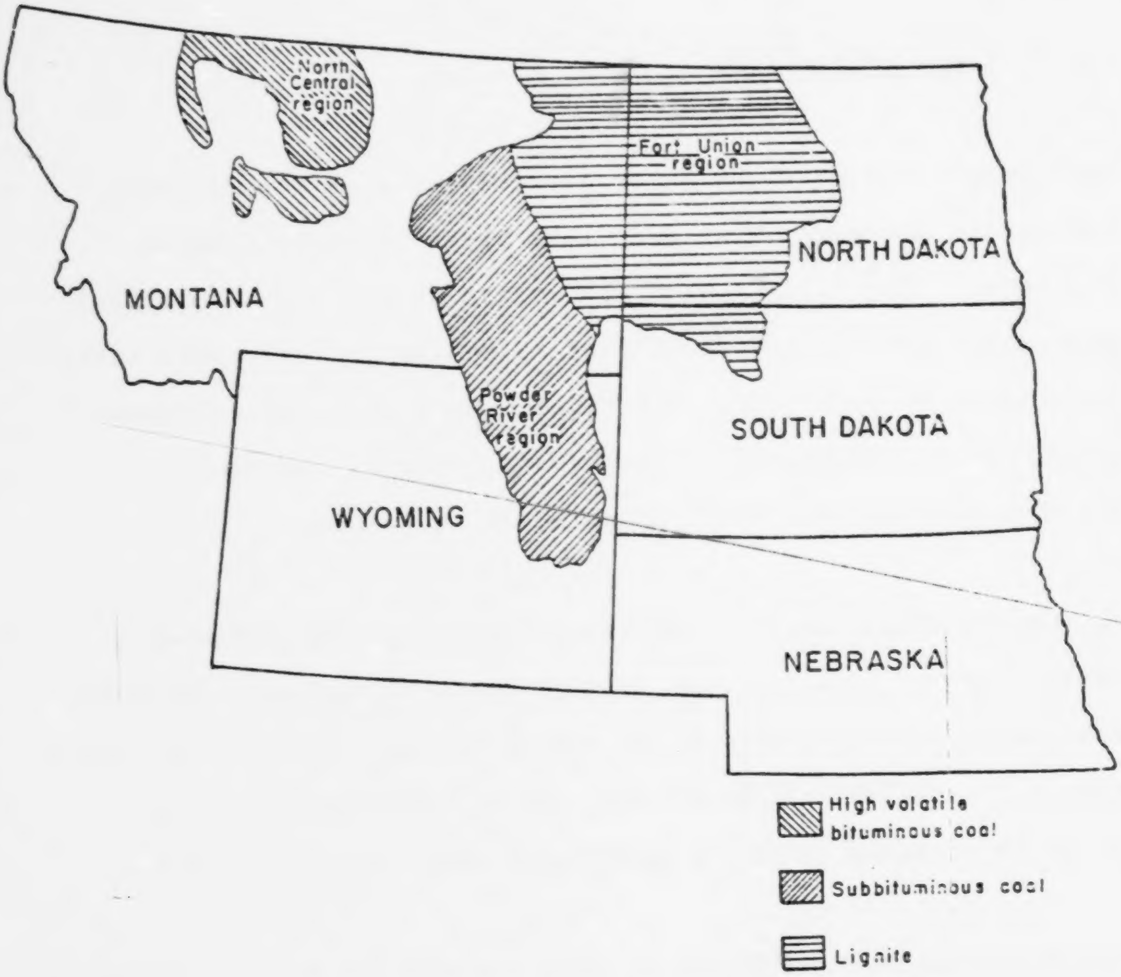
The motivation for this project originates from fears of negative environmental impacts. This motivation tends to ignore any positive environmental impacts through enhancement of soil, water, or air quality in ways which may improve habitats of living organisms. As with any research, careful scrutiny of data for scientific merit beyond project objectives and for interpretation of any positive as well as negative results is certainly proper.

1.2 Scope of Problem

Development and utilization of coal reserves of the Old West Region are underway, with even more significant utilization projected. The "mine-mouth" production of coal for electrical generation and conversion of coal to synthetic fuels pose serious environmental questions. The significance of these environmental questions is emphasized by the expanse of coal reserves which could potentially be utilized as shown in Figure 1.

Mine-mouth operation of lignite coal-fired energy conversion facilities has occurred due to high costs of transporting this coal over long distances to an energy conversion facility. As a result, large quantities of coal can be consumed and waste products released within a relatively small geographic area.

The environmental questions of coal utilization are not unique to Montana, North Dakota, and Wyoming, since the states of South Dakota and Nebraska will, no doubt, continue to use some of the coal exported from the other three states which are richer in coal deposits. As an example, coal is being transported from southwestern North Dakota to a power generating station in northeastern South Dakota. Thus, environmental questions are regional in scope.


North Central region
Fort Union region
NORTH DAKOTA
MONTANA
Powder River region
SOUTH DAKOTA
WYOMING
NEBRASKA
High volatile bituminous coal
Subbituminous coal
Lignite

SOURCE: Federal Energy Administration 1975

Figure 1. Coal production areas of the Old West Region.

Existing levels of energy activities in States of the Old West Region are shown in Table 1. Increases in electrical generating capacity, or establishment of facilities for production of synthetic natural gas and synthetic petroleum, means more coal consumption, even when considering improvements in thermal efficiency of future facilities. An increase in coal consumption can be expected to result in increased emissions of processed wastes, even when best available control technology is applied.

In North Dakota, specifically, a marked increase in coal development has occurred with the past three years. Table 2 describes the growth of electrical generating capacity which is occurring in this State. All of the generating capacity is located within a circular area having a radius of approximately 50 kilometers. By 1983, there will be 14 lignite-fired electrical units producing 4,018 megawatts of electricity from an annual coal consumption of 22.7 million metric tons.

Environmentally related issues and impacts from process waste emissions may become significant factors in siting new facilities, in the density of the facilities, and in the type and degree of control over waste emissions. The purpose of this project is to resolve some of the uncertainties of the environmental issues related to the redistribution of elements.

TABLE 1

PROJECTED INSTALLED ELECTRICAL GENERATING CAPACITY

State	Installed Capacity (megawatts) Existing January 1974	Most Probable 1985	Most Probable 2000
Montana	345	3,101	9,100
Nebraska	1,534	3,670	6,920
North Dakota	862	4,125	14,910
South Dakota	252	1,504	6,060
Wyoming	1,535	3,893	8,455
Regional Total	4,528	16,293	45,445

SOURCE: Northern Great Plains Resources Program
Atmospheric Aspects Work Group Report
December 1974

TABLE 2

INSTALLED ELECTRICAL GENERATING CAPACITY IN NORTH DAKOTA

	Number of Facilities	Cumulative Megawatts
1974	7	728
1975	8	1,168
1977	9	1,608
1979	11[1]	2,598
1981	12[1]	3,138
1983	14[1]	4,018

---

[1] Additional facilities under construction.

1.3 Environmental Significance of Project

Elements are common throughout the environment. Soil, water, and aerosol contain elements in variable concentrations.

Many elements are essential for proper nutritional-biological functioning of living organisms. Deficiencies of essential elements have occurred when the nutritional availability of the elements has changed. Excessive concentrations of some elements have been demonstrated to interfere with the normal availability of other elements, thereby creating a deficiency condition.

Increases in concentrations (enrichment) of certain elements in the soil, through contamination, has produced documented deleterious effects. Molybdenum enrichment of soil surrounding an uraniferous ashing plant was found to be the cause of a molybdenosis in grazing cattle and sheep (1). Rainfall runoff from clay spoil piles produced by mining the clay transferred particles bearing copper, cobalt, and molybdenum down a flood plain where cattle grazing on grasslands developed symptoms of chronic molybdenosis (2). Effects of element enrichment within aerosol, water and soil can have a direct effect upon living organisms, or an indirect effect via translocation in the ecosystem food chain of living organisms.

Considerable research information on elements in water and soil and the nutritional value of these elements to living organisms is available in the literature (3). Much of this information, although useful, cannot be directly utilized to assess environmental impacts of existing or proposed new coal-fired facilities.

1.4 Phase I of the Project

A two-year investigation of the background concentrations of certain elements in soil and vegetation was conducted by the North Dakota State Department of Health during 1976 and 1977 (3). This investigation focused on a wide-area sampling of soil and vegetation in Western North Dakota. The area, 2,400 square miles, includes sites of many of the active and proposed new facilities listed in Table 2.

In addition to soil and vegetation samples coal samples were obtained from the four operating mines in the area. Analysis of certain element concentrations were conducted on these samples. A computer model of atmospheric diffusion was used as a tool to estimate dry deposition (atmospheric fallout) of fly ash emitted from stacks of the facilities.

The broad objective of Phase I was to determine effects of certain elements, which were redistributed by coal-fired energy conversion facilities, on living organisms. The study concluded, on the basis of the soil data, coal data, and the rate of deposition (surface accumulation), that environmental enrichment or increased environmental exposure (through increased air concentration of elements) would not cause detectable adverse effects on living organisms over a time period of one year.

Although Phase I involved collection of 205 soil samples, the density of sampling sites was inadequate to detect patterns of the element concentrations in soils which may be attributable as atmospheric deposition from plumes of coal-fired facilities. The results of Phase I did not provide any evidence of enrichment of the elements in the study area. However, this study provided a very valuable base of sampling experience necessary for the Phase II Project.

1.5 Objectives of Project

Although considerable research information on elements is available, the information does not provide rates of ecosystem enrichment from coal-fired facilities which can be used to assess environmental consequences of enrichment. In order to establish rates of enrichment, field data must be gathered.

The objectives of Phase I have been modified for this project to reflect Phase I experience and results and to expand the project's capability of assessing environmental consequences of trace element enrichment. The objectives of this project are as follows:

1) To establish baseline concentrations of certain elements in aerosol, soil, water, and vegetation in the vicinity of a specific coal-fired facility.

2) To determine the rate at which the elements will be introduced to the ecosystem by air waste streams of the coal-fired facility.

3) To examine baseline data for evidence of current influences by the coal-fired facility.

4) To identify and evaluate any impacts from the disposal of solid and liquid process wastes produced by the facility.

5) To identify and evaluate mechanisms by which elements transfer within the ecosystem among soil, water and vegetation components.

6) To examine the data as evidence for a need for developing regulatory controls of processed wastes containing elements.

The project is exploratory: that is, data will be examined for possible cause-effect relationships upon which hypothesis of effects can be prepared. Therefore, future project(s) will be necessary to confirm conclusions and hypotheses based upon independent sets of data.

1.6 Related Projects

Several relevant related projects were in progress in the Old West Region during the period of this project. These projects also have a direct bearing on the assessment of the environmental consequences of coal-fired facilities.

An extensive project on "the bioenvironmental impact of a coal-fired power plant" is underway in the area surrounding a power plant at Colstrip, Montana (4). This project is focused on "the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects, and control of pollutants in lake systems; and the development of predictive models on the movement of pollutants in the biosphere."

Growth chamber and greenhouse studies were conducted by the Botony, Mechanical Engineering, and Soils Departments at North Dakota State University concerning the effects of enriched soil concentrations of certain elements on dominant vegetation types in west-central North Dakota (5). The results of these studies are directly applicable to objective 5 of this project relating to transfer of trace elements among the soil, water, and vegetation elements of the ecosystem.

The N.D. Geological Survey, at Grand Forks, is currently conducting surveys of metal concentrations in the ground water surrounding the mine and coal-fired facility studied under this project

(6). Although conclusions are not yet available, the ground water research will provide insight into mine burial of scrubber sludge and precipitator bottom ash from the facility. The ground water study is particularly applicable to objective 4 of this project.

Since objectives 4 and 5 are being addressed in considerable detail by other research agencies at levels of effort well beyond the available resources of this project, this project has not specifically addressed these objectives in field sampling and data analysis.

2. PROJECT DESIGN

2.1 Approach to Problem

Assessments of the magnitudes of impacts created by the redistribution of facility process wastes must be preceded by a system of measurements (1) to establish whether a redistribution and enrichment is occurring, (2) where in the ecosystem the enrichment occurs, (3) the relative departure from baseline conditions, and (4) resulting influences on the biosphere.

A project design which can detect the occurrence of redistribution of elements must maximize the likelihood of detection by selecting a proper sampling and statistical scheme. Since this project was, by concept, an exploratory project, statistical methods for data analysis were not specified in advance. Project resources, including funding, dictated the limits of the selected sampling scheme and depth of sample analysis.

An atmospheric transport and deposition computer model was used as a tool to identify an appropriate sampling grid. Input into the model included anticipated emission rates of elements, coal-fired facility stack and stack gas characteristics, and climatological wind velocity and atmospheric data. This analysis indicated that maximum ground-level air concentrations of elements would occur about six kilometers toward the north-northwest and southeast of the facility. Further, the model indicated that the maximum deposition of elements from dryfall and wetfall would occur adjacent to the facility and that deposition rapidly decreases exponentially from the facility.

Therefore, it was determined that field sampling of aerosol, soil, and vegetation must be concentrated in regions that are northwest and southeast of the facility and within areas of the strongest gradients of ground-level air concentration and deposition. Furthermore,

1) the area should contain a single coal-fired facility reasonably isolated from the influence of other facilities,

2) the area around the facility should include undisturbed native prairie to reduce the influence of anthropogenic activities,

3) the area surrounding the facility should contain a watershed drainage basin and aquatic impoundment for evaluation of influences of process wastes on an aquatic system,

4) the area should be of size to provide adequate sampling for evaluation, and

5) the facility should have an extended history of operation in the area.

While the fifth criteria does not provide for field sampling in an area prior to start-up of operation, it does provide a history of enrichment in the sampling area for interpretation of data without the luxury of assurance that the field sampling will be repeated at a future date.

2.2 Facility and Study Area Description

The location and operation of the Milton R. Young Power Plant satisfies the criteria above and presents a unique opportunity to examine effects of a coal-fired power plant upon the aquatic environment. This facility, owned and operated by Minnkota Power Cooperative and Square Butte Power Cooperative, is located near Center, North Dakota, about 56 kilometers northwest of Bismarck. A photograph of the facility is shown as Figure 2.

The facility is capable, under normal operating conditions, of consuming 523,000 kilograms per hour of lignite coal for producing 675 megawatts of electrical power. Unit I of the facility was placed into operation in 1970 and Unit II in 1977: Units I and II produce 235 and 440 megawatts, respectively. Electrostatic precipitators are operated on both units to remove particulates, and scrubbers are operated on Unit II to remove sulfur dioxide (SO_2) gas.

The facility cycles about 72,000,000 liters per hour of cooling water from an adjacent lake, Nelson Lake, which is also owned by

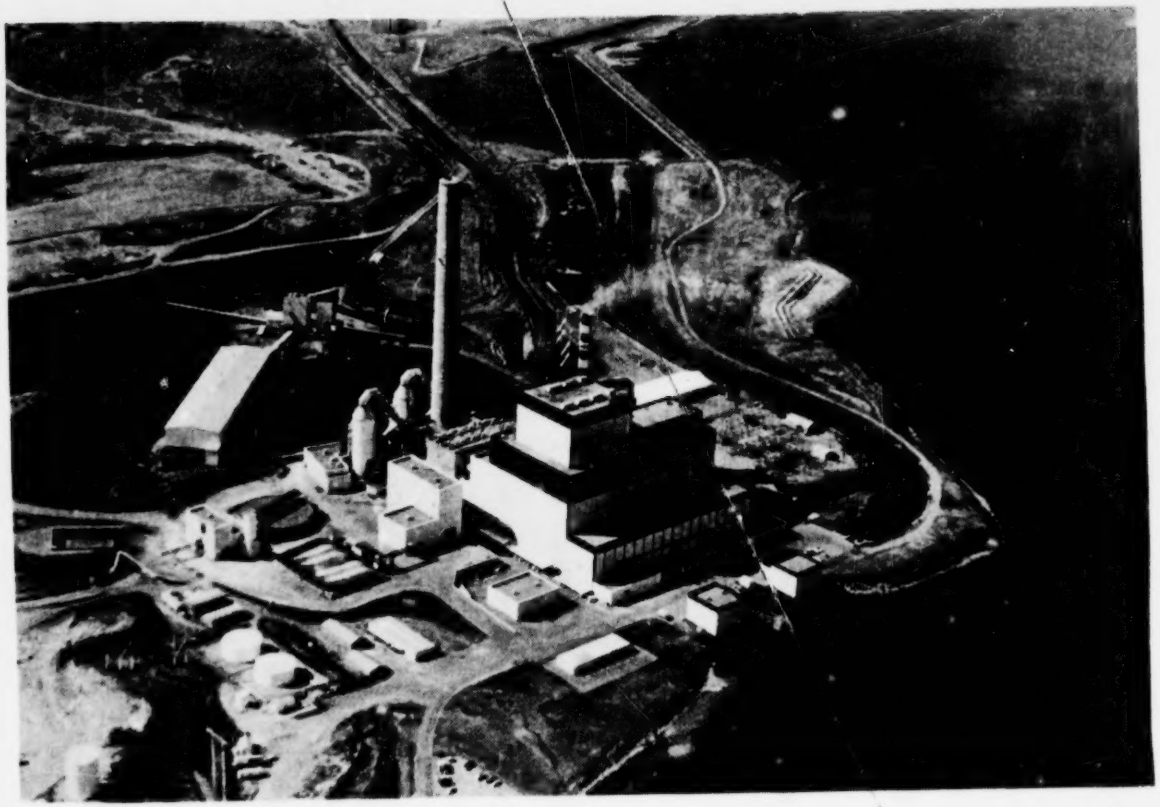


Figure 2. A photograph of the Milton R. Young Power Plant.

Minnkota Power Cooperative. This lake covers 260 hectares, contains 11.1 million cubic meters of water, and is about 9.5 meters deep at its greatest depth.

Two watershed basins supply drainage precipitation water to the lake. Square Butte Creek and its watershed basin lie to the northwest of Nelson Lake, and Hagel Creek and its drainage basin lie to the west. The area of these two watersheds is 351 square kilometers. The average annual runoff from precipitation and snowmelt is about 11 million cubic meters. A pipeline provides water from the Missouri River when watershed runoff is not sufficient to maintain adequate volume of cooling water. This pipeline has been used infrequently since constructed.

The coal field, which supplies coal for consumption by the Milton R. Young Plant, lies to the west of Nelson Lake between Hagel Creek and Square Butte Creek. The coal field lies within watershed basins of the lake. Coal is hauled from the coal field to the facility site where it is crushed and stored for immediate use in enclosed storage and an open stockpile. A stockpile of 635,000 metric tons is maintained for emergency use.

Figure 3 is an aerial photograph which shows the area surrounding Nelson Lake. The area is primarily farmland; cropland is interspersed with native grassland which is used for animal grazing. The rural community of Center is located about six kilometers northwest of the lake. Square Butte Creek continues downstream from Nelson Lake to the southeast.

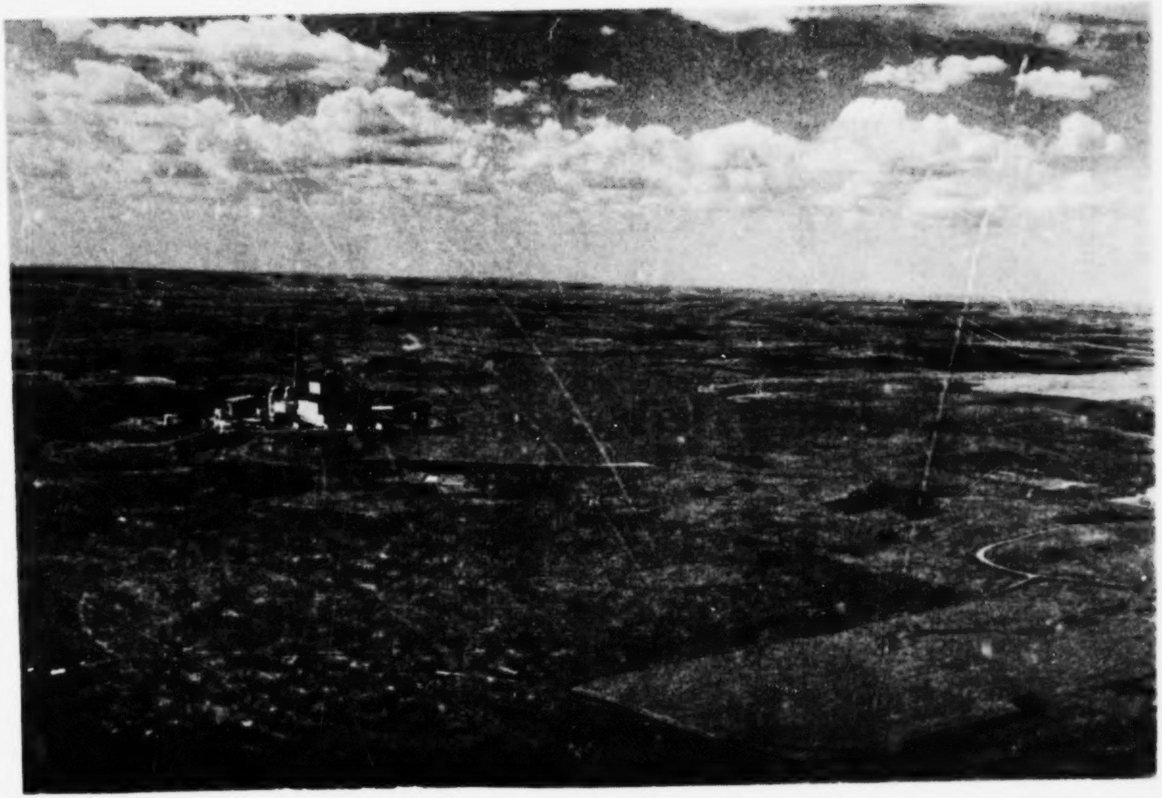


Figure 3. An aerial photograph of Nelson Lake and surrounding area.

Surface winds during the months of April through October occur most frequently from the southeast quadrant. Thus, surface winds direct plumes from the two stacks of the facility more frequently over watershed basins of Nelson Lake than over other directions. Annual average precipitation in the area is 45.2 centimeters, and precipitation during the growing season of April through October is 34.5 centimeters.

Nelson Lake supports fish species commonly known as Northern Pike, Bluegill, and Bass. Public use of the lake has been promoted by the power company; sport fishing and boating activities are frequently observed on the lake.

Element enrichment of Nelson Lake could occur from several sources; (1) facility air emissions, deposition, and precipitation washout over watersheds, (2) soil erosion upstream and sediment, (3) mine drainage, (4) coal stockpile drainage, and (5) facility water discharge. The arrangement of the energy conversion facility, the lake used for cooling water, the coal field, and the surrounding terrain and watersheds provides a unique opportunity to monitor effects of the coal-fired power generating facility on the aquatic ecosystem, see Figure 3.

2.3 Conceptual Design

The activity of measuring the levels of element concentrations of environmental receptors, such as water, soil, and vegetation, cannot resolve the environmental issues of the redistribution of elements without tracking the redistribution process. Cause-effect relationships between the source (coal-fired facility) and a receptor (such as a vegetation species) must be predicated upon explanations for the process by which physical transport of the element occurs.

The conceptual framework of the design of field measurement activities is portrayed in Figure 4. The figure demonstrates the research activities of this project.

Concentrations of the individual elements in coal vary horizontally and vertically through coal seams. Measurements of coal concentrations of elements not only provide evidence of the quantities of elements available for redistribution, but provide insight into the variability of environmental consequences which might be expected.

The elements contained in the consumed coal must exit the facility process waste streams: a portion is removed with scrubber sludge, another portion with precipitator ash, and the remaining portion escapes in stack flue gas as particles and/or gases. The amounts of certain elements emitted with the stack flue gases vary from 0.3 to 98 percent of respective elements contained in coals (7). Concentrations of certain elements are greater for smaller fly ash particles than for the larger fly ash particles (8, 9). The rate at which particles reach the ground surface depends primarily on particle size. Vegetation intake through leaves may vary with each element and the form of the element (particle or gas).

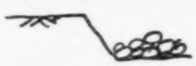
	COAL MINE	Bulk Concentrations of Trace Elements in Coal Reservoir
	STACK EMISSIONS	Rate and Form of Emissions, (Particulate and/or Gas and Particle Size)
	ATMOSPHERIC TRANSPORT & DEPOSITION	Computer Numerical Modeling, Plume Dispersion and Atmospheric Fallout of Emissions
	AEROSOL	Evidence of Soil and Vegetation Exposure, Airborne Dust Concentrations
	SURFACE RECEPTORS	Soil and Vegetations Concentrations at Sites in Study Area
	WATER RECEPTOR	Stream Water Drainage Concentrations, Process Waste Water Concentrations and Reservoir Water Concentrations.

Figure 4. Research activities of the project.

Winds blow more frequently from the northwest or southeast over western North Dakota. Greater wind speeds increase the diffusion of stack flue gas contaminants causing lower surface air concentrations. Seasonal variations of these and other atmospheric parameters, such as temperature, can be included as input data to a computer mathematical model of the diffusion process. The output of the model identifies regions within an area which may have been more influenced by higher atmospheric concentrations and deposition. In addition, computer modeling can be used to assess future rates of deposition and the combined impacts of several "adjacent" coal-fired facilities.

Confirmation of aerosol enrichment of elements over environmental receptors of water, soil, and vegetation becomes necessary to demonstrate that these receptors have been exposed to the plume of the coal-fired facility. This can be achieved by surface air sampling in the study area of suspended particulates, analysis for concentrations of elements, analysis of source element emissions, and applying chemical elemental balance techniques (10).

The computer modeling studies indicate how and where the stack flue gas would be transported to environmental receptors and the aerosol studies indicate whether significant increases in ground-level air concentrations of elements occur. However, analysis of concentrations in environmental receptors, such as water, soil, and vegetation, is necessary to identify the space and temporal variability of element concentrations in these receptors.

Patterns of the space and temporal variability must be related physically and statistically to source emissions before a potential impact can be identified.

The statistically sufficient number of samples which could describe the variance of elements in environmental samples was not known prior to the project. The variance of the data can be expected to be related to the geochemistry of the study area. An area, which has a "homogeneous" soil type, would conceptually require fewer soil samples for a statistical study of soil enrichment. Therefore, a sampling grid of soil and vegetation was necessary to identify the spacial (distance and direction) variability of element concentrations around the coal-fired facility.

Snowmelt, rainfall, and watershed runoff may concentrate elements in stream water, lake water, and selected stream and lake sediments. Measurement of selected element concentrations in these receptors within the lake, as well as upstream and downstream, will provide a baseline of existing levels in an aquatic ecosystem adjacent to the coal-fired facility.

2.4 Assessment of Environmental Consequences

The conceptual field measurement program described in Section 2.3 above will provide information on current levels of certain trace elements contained in specific environmental receptors. The resources available for the project were not sufficient to investigate the consequences of trace element enrichment on the quality and production capacity of soil and water and on vegetation quality and yield. In anticipation of this limitation, a literature search of information pertaining to nutritional aspects of trace elements was conducted during the project.

3. EXPERIMENTAL METHODS

The primary area chosen for measurement of element concentrations in environmental receptors is that area within twelve kilometers (seven miles) surrounding the Milton R. Young Power Plant.

For a detailed description of all components contained in this section, readers are referred to Appendices A, B, and C.

3.1 Sources Surrounding Study Area

A criteria for selection of the study area was that the area should be isolated from potential influences of sources of elements located outside the area. Four additional coal-fired facilities were operating during the summer of 1978 and the spring of 1979 when the project data was gathered. The four facilities are: Basin Electric's Leland Olds Power Plant at Stanton, United Power Cooperative Power Plant at Stanton, Montana-Dakota Utilities (MDU) Power Plant at Beulah, and the MDU Heskett Power Plant at Mandan. An additional facility at Washburn terminated operation in 1969.

The locations of these facilities in relationship to the field study area and operating characteristics are shown in Figure 5 and Table 3, respectively. The data presented in Table 3 are required input parameters for a computer model assessment of the influence of these facilities on the study area.

TABLE 3

COAL ENERGY CONVERSION FACILITY DATA

Facility	Owner	Unit Number	Start-up Date	Capacity (megawatts)	Coal Feed Rate (kilograms/hour)	Emission Control Device	Stack Height (meters)	Stack Diameter (meters)	Stack Gas Speed (meters/second)	Stack Gas Temperature (degree C)
Existing Sources:										
MDU, Beulah	Montana Dakota Utilities	1 & 2	1928	13.5	8,410	none	22.6	1.5	9.4	205
		3, 4 & 5	1948		10,500	EPA1/	30.5	2.3	14.5	255
Heskett, Mandan	Montana Dakota Utilities	1	1954	25	22,475	multicyclone	91.5	2.1	15.8	172
		2	1963	66	49,100	multicyclone	91.5	3.7	12.7	154
Leland Olds, Stanton	Basin Electric Power Coop.	1	1966	216	155,360	ESP	106.7	5.3	16.7	178
		2	1975	440	330,970	ESP	152.4	5.7	28.1	204
UPA, Stanton	United Power Association	1	1966	140	79,545	ESP	77.7	4.6	27.4	187
MRY, Center	Minnkota Power Coop.,	1	1970	235	181,820	ESP	91.5	5.8	21.3	177
	Square Butte Power Coop.	2	1977	440	340,910	ESP & SO_2 scrubber	167.7	7.6	20.3	149
Facilities Under Construction:										
Coal Creek, Underwood	United Power Association/ Cooperative Power Association	1	1979	545	366,360	ESP & SO_2 scrubber	201	6.7	27.2	131
		2	1980	545	366,360	ESP & SO_2 scrubber	201	6.7	27.2	131
Coyote, Beulah	Montana Dakota Utilities/ Ottertail Power Coop.	1	1981	440	286,820	fabric filter & spray dryer scrubber	152	7.3	17.5	57
Antelope Valley, Beulah	Basin Electric Power Coop.	1	1980	440	340,360	ESP & SO_2 scrubber	183	7.0	22.3	83
		2	1983	440	340,360	ESP & SO_2 scrubber	183	7.0	22.3	83

1/ ESP - Electrostatic Precipitator.

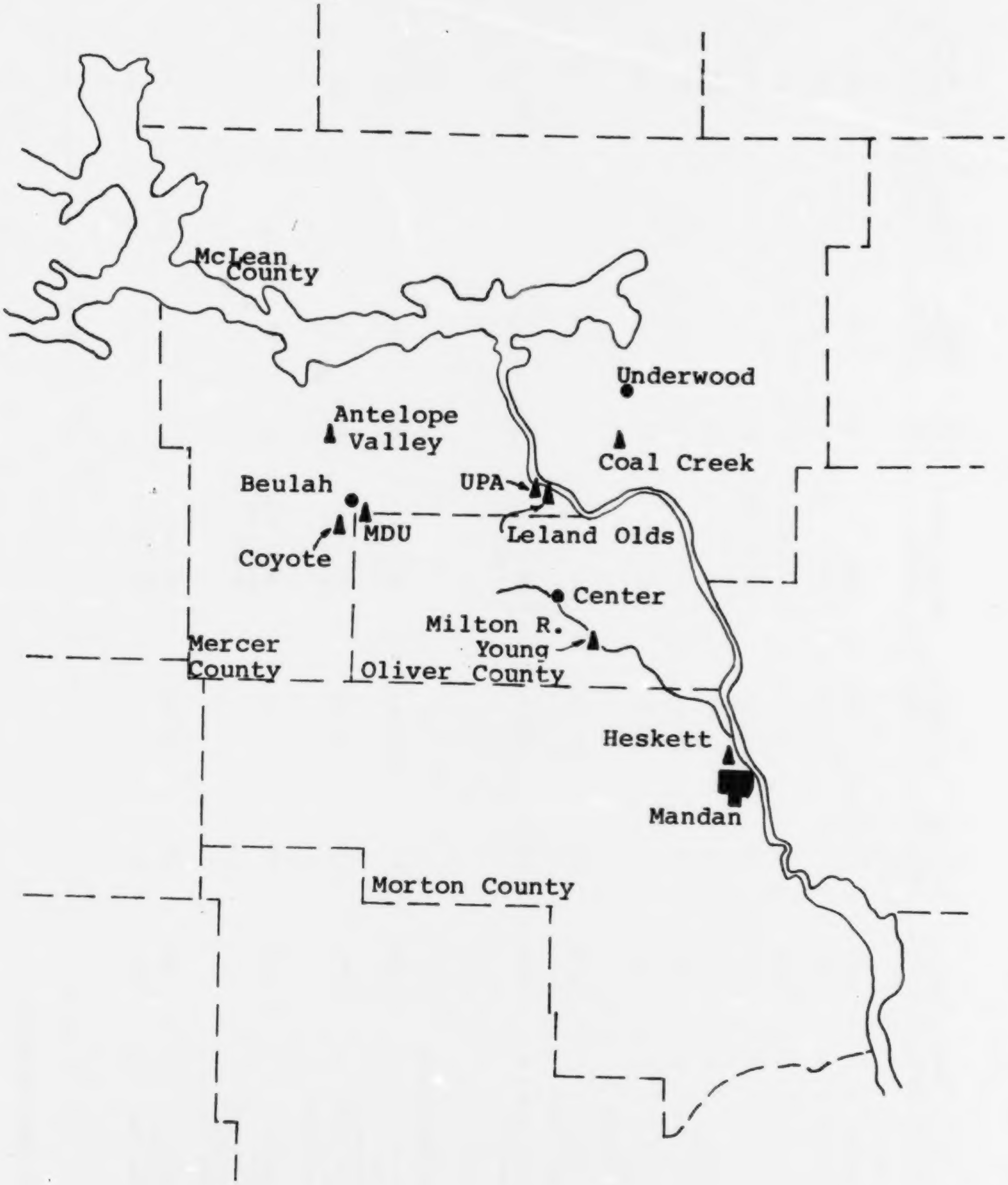

McLean County
Underwood
Antelope Valley
Coal Creek
Beulah
UPA
MDU
Leland Olds
Coyote
Center
Milton R. Young
Mercer County
Oliver County
Heskett
Mandan
Morton County

Figure 5. Map of the locations of coal-fired energy conversion facilities.

3.2 Power Plant Description

The Milton R. Young Power Plant consists of two generating units both equipped with cyclone-fired boilers. Both units have hotside electrostatic precipitators: Unit II is also equipped with a wet scrubber for sulfur dioxide (SO_2) removal. The maximum gross output for Unit I is 265,000 kilowatt, and Unit II is 476,790 kilowatt. The proximate analysis of the coal burned at the plant during the sampling period was: ash-8.3%; sulfur-0.8%; moisture-37%; BTU/lb-6,600.

3.3 Coal Sampling Procedures

Lignite coal, supplied to the electrical generating facilities, comes from nearby mines. Samples of coal from the Baukol-Noonan, Glenharold, and Indianhead mine were obtained from the coal conditioners at the Milton R. Young, Leland Olds, and United Power Cooperative Power Plants, respectively. Samples of coal from the Knife River Coal Co., South Beulah Mine, were obtained off of the coal conveyor at the Heskett Power Plant. The samples were oven dried at 50 degrees Centigrade, ground, and re-dried pending analysis.

3.4 Stack Sampling Procedures

In-stack sampling was performed on Unit II of the study facility at sampling ports located at the 122 meter level. A Nutech Corporation EPA-method-five sampling train was used as shown in Figure 6. Fly ash particle size fractions were obtained with a seven-stage University of Washington Mark III Cascade Impactor mounted at the end of the sampling probe (11). The fly ash size fractions were collected on laminated Teflon substrate. The heated stainless steel probe permitted simultaneous collection of vapor-phase constituents in an impinger train located outside the stack.

3.5 Atmospheric Modeling

A computer program developed at the Oak Ridge National Laboratories was modified for the specific application of this project (12, 13). A primary modification made to the program allowed multiple receptor locations so that mapping of surface deposition and air concentration were possible.

Input into the program consists of source coordinates, receptor coordinates, wind data, temperature data, rainfall data, and source characteristics including element emission rates. Output of the model consists of a listing of wet and dry deposition and ground-level air concentrations for each receptor. Another computer routine analyzed the data to produce the isopleth maps shown in this report. These programs were executed on an IBM 370-158 operated by the State of North Dakota for State agencies.

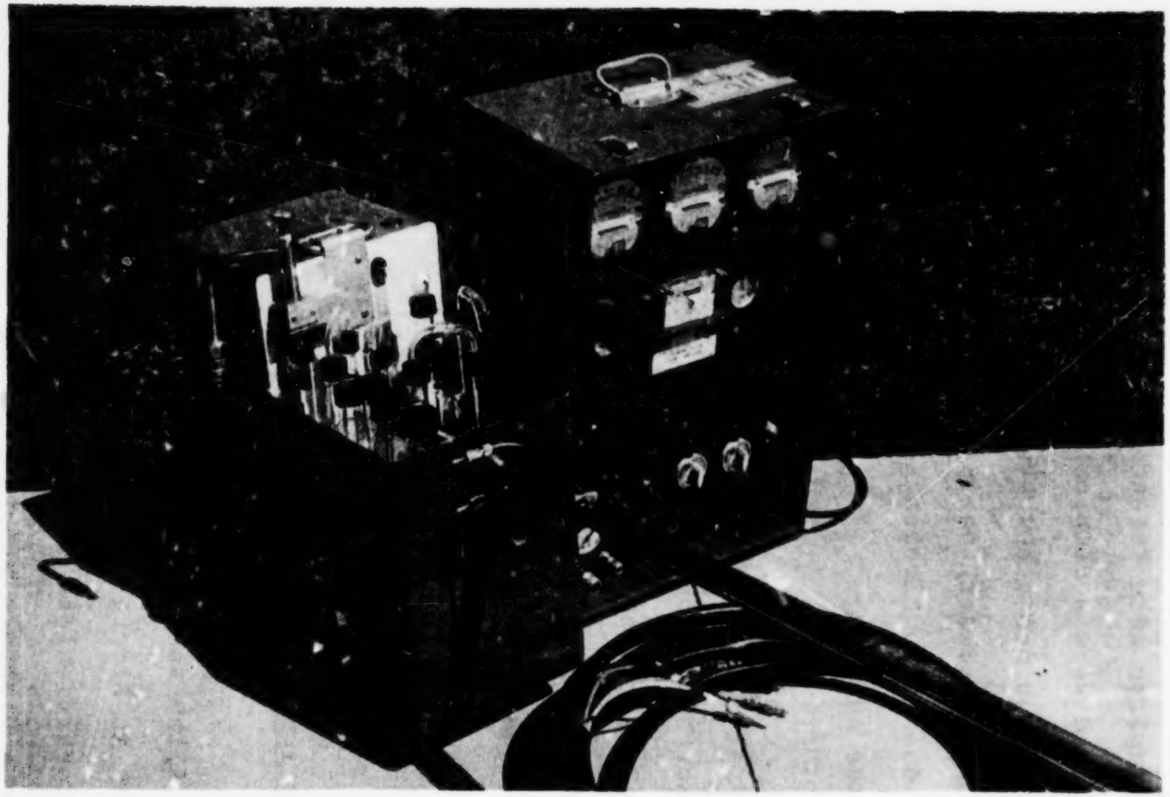


Figure 6. A photograph of the stack flue gas sampling apparatus.

3.6 Ambient Aerosol Sampling

3.6.1 Site Location

Four aerosol samplers were located at sites shown in Figure 7. The sites selected were a compromise from more desirable locations based upon projected areas of maximum ground-level air concentrations of elements, see Section 4.3. The compromise was necessary due to requirements for site accessibility and electrical power supply.

The sites were identified as A1 through A4. Sites A1 and A3 were located northwest and southwest of the facility, respectively. Sites A4 and A2 were located west-northwest and east-southeast of the facility, respectively. Sites A1 and A3 comprised a wind upstream-downstream pair, and A2 and A4 a second upstream-downstream pair. A site, when located downstream, was considered to have been in the path of stack plumes.

3.6.2 Description of the Sampling Apparatus

A photograph of the sampling apparatus, or Stacked Filter Unit (SFU), is shown in Figure 8. A modified Research Appliance Company, Total Particulate Membrane Sampler with the attached SFU was mounted on a platform placing the unit about four meters above the ground (14). The aerosol particles were collected on 47-millimeter diameter 12-micrometer (μm) and 0.4-μm Nuclepore filters using Nuclepore aerosol holders and multiple holder adapters.

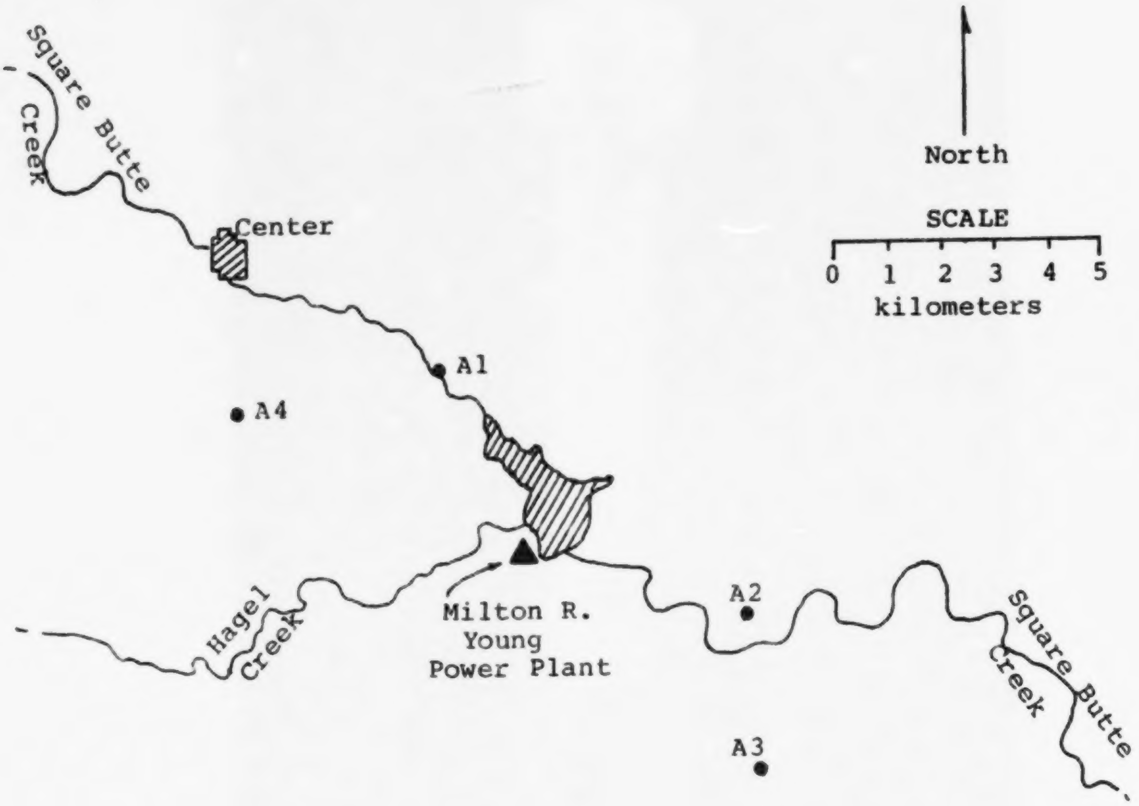

Square Butte
Creek
Center
North
SCALE
0 1 2 3 4 5
kilometers
A1
A4
A2
A3
Hagel
Creek
Milton R.
Young
Power Plant
Square Butte
Creek

Figure 7. Map of aerosol sampling locations and corresponding numbers.

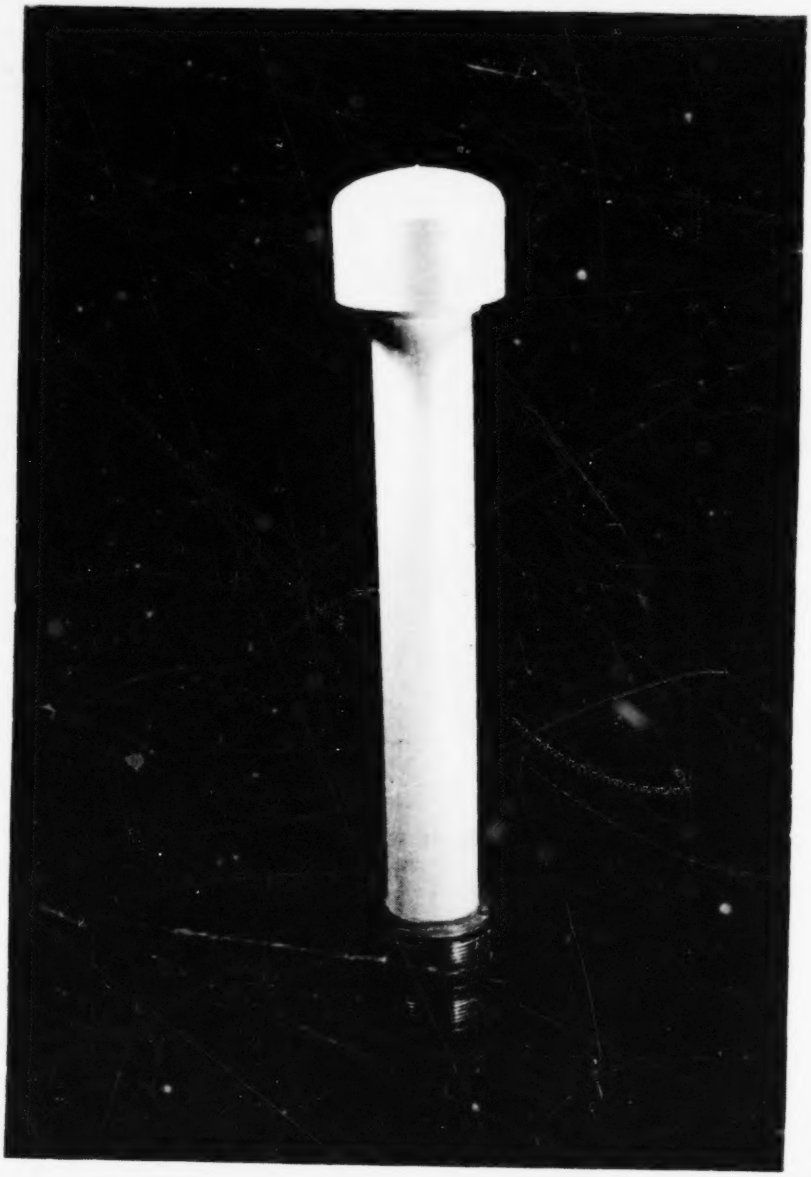


Figure 8. Photograph of the aerosol stacked filter unit.

3.6.3 Operation of the SFU

Sampling of the ambient aerosol began on May 25, 1978, and ended on October 21, 1978. Filters were changed once daily on each sampler at approximately 8 a.m. CST. Thus, one set of filters was scheduled for collection of a 24-hour sample for each day of the sampling period. Since equipment was not always operational, a few samples were not collected.

The volume flow rates of the vacuum pumps were calibrated once each week with a mass flow meter. The air flow through the filter heads was monitored with a vacuum gauge. The gauge was read by an operator at the start and end of each sampling day. The average flow during the sampling day was assumed to be a linear average of the flows at the start and the end of the day.

The filters were weighed to a precision of 10 micrograms using an electrobalance. Each site had two SFU's so that the operator could load and unload a complete unit at her headquarters to minimize contamination and other handling problems.

3.7 Snow Sampling

3.7.1 Site Selection

Sites for collection of fresh surface snow samples were selected along a 6.5 kilometer radius downwind of the facility from the east-southeast through south-southwest directions. In addition, sites were selected along one transect through the facility at distances between 1 and 11 kilometers. A map of these site locations is shown in Figure 9.

3.7.2 Collection Procedure

Collection of the 19 samples began at 9:15 a.m. on January 24, 1979, and was completed by 3:15 p.m., the temperature did not exceed -13 C. With the exception of number 17_S and E_S, the samples are surface samples consisting of the top 1 centimeter of snow. Samples were taken with a stainless steel spatula from an area about 1 meter square. Upon collection, the samples were placed in Nalgene zip lock polyethylene bags.

3.8 Precipitation Sampling

Precipitation was collected throughout the summer of 1978 with an Aerochem Metrics Model 201 Automatic Sensing Wet/Dry Precipitation Collector (Figure 10), located at air sampling site A2.

3.9 Aquatic Sampling

Weekly sampling of twelve sites was conducted from mid-May through September of 1978 and for four weeks in April, 1979. Surface samples were taken from the two streams (Hagel Creek

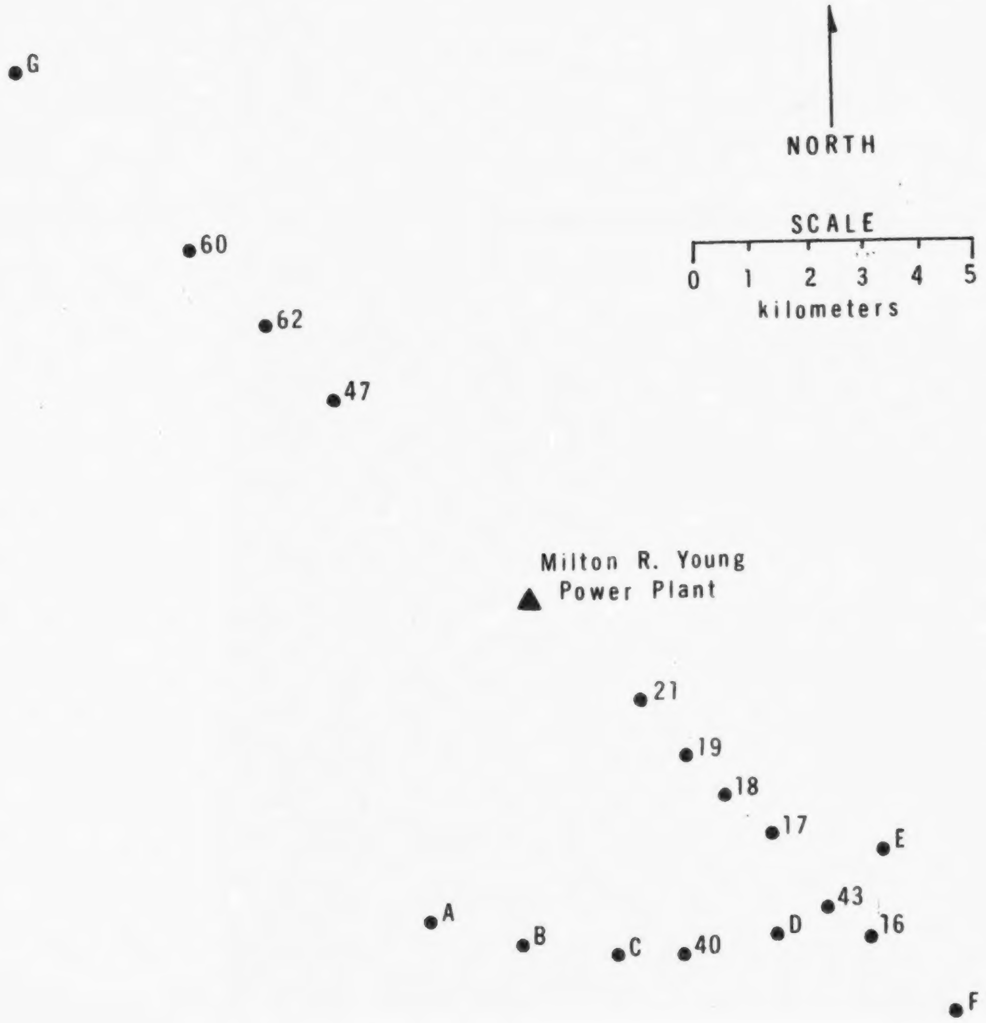

NORTH
SCALE
0
1
2
3
4
5
kilometers
G
60
62
47
Milton R. Young
Power Plant
21
19
18
17
E
43
16
A
B
C
40
D
F

Figure 9. Map of snow sampling locations and corresponding numbers.

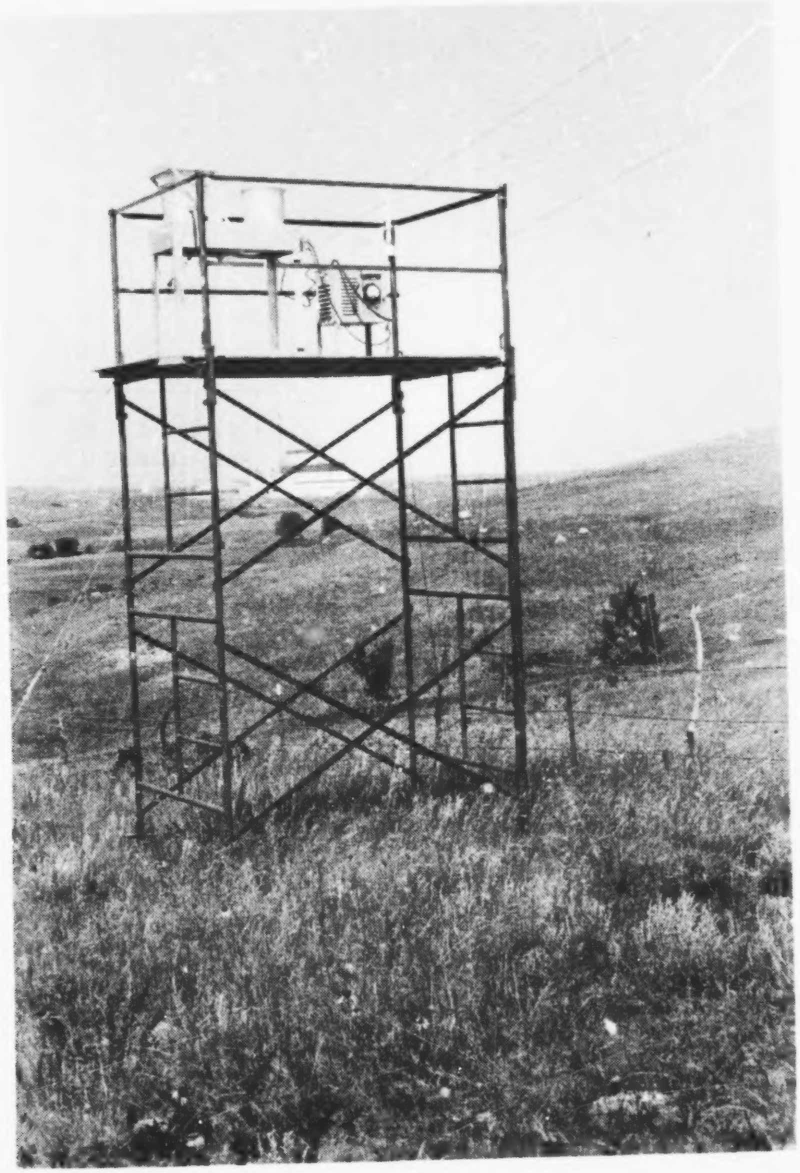


Figure 10. Photograph of aerosol sampling site A2 showing installation of precipitation collector and aerosol sampler.

and Square Butte Creek) that form the upper reaches of the Nelson Lake Watershed and from Square Butte Creek that forms the lower reaches of the watershed. Samples at five sites on Nelson Lake, plus samples of sluice water and cooling water discharge, were also taken.

Figure 11 is a map showing locations of the Nelson Lake and upstream sites. Site 4 at the end of the cooling water discharge canal contains the discharge water at site 9 and the stream water from Hagel Creek, site 2. The locations of downstream sites are shown in Figure 12.

The watershed drainage areas of Square Butte Creek and Hagel Creek are shown in Figure 12. Also shown are the locations of downstream water sampling sites 10 and 11. Since water was not discharged from Nelson Lake dam during the 1978 sampling period, sites 10 and 11 water samples included spring discharge, snowmelt runoff, and rainfall runoff.

3.10 Soils

3.10.1 Site Selection

The sampling grid was based on 16 evenly spaced radials originating at the study facility as shown in Figure 13. The 16 radials represent the standard 22 1/2 degree wind sectors. Sixty-four plots, 15x30 meters in size, were sampled. A 10-centimeter (10-cm) core sample was taken at each plot. An

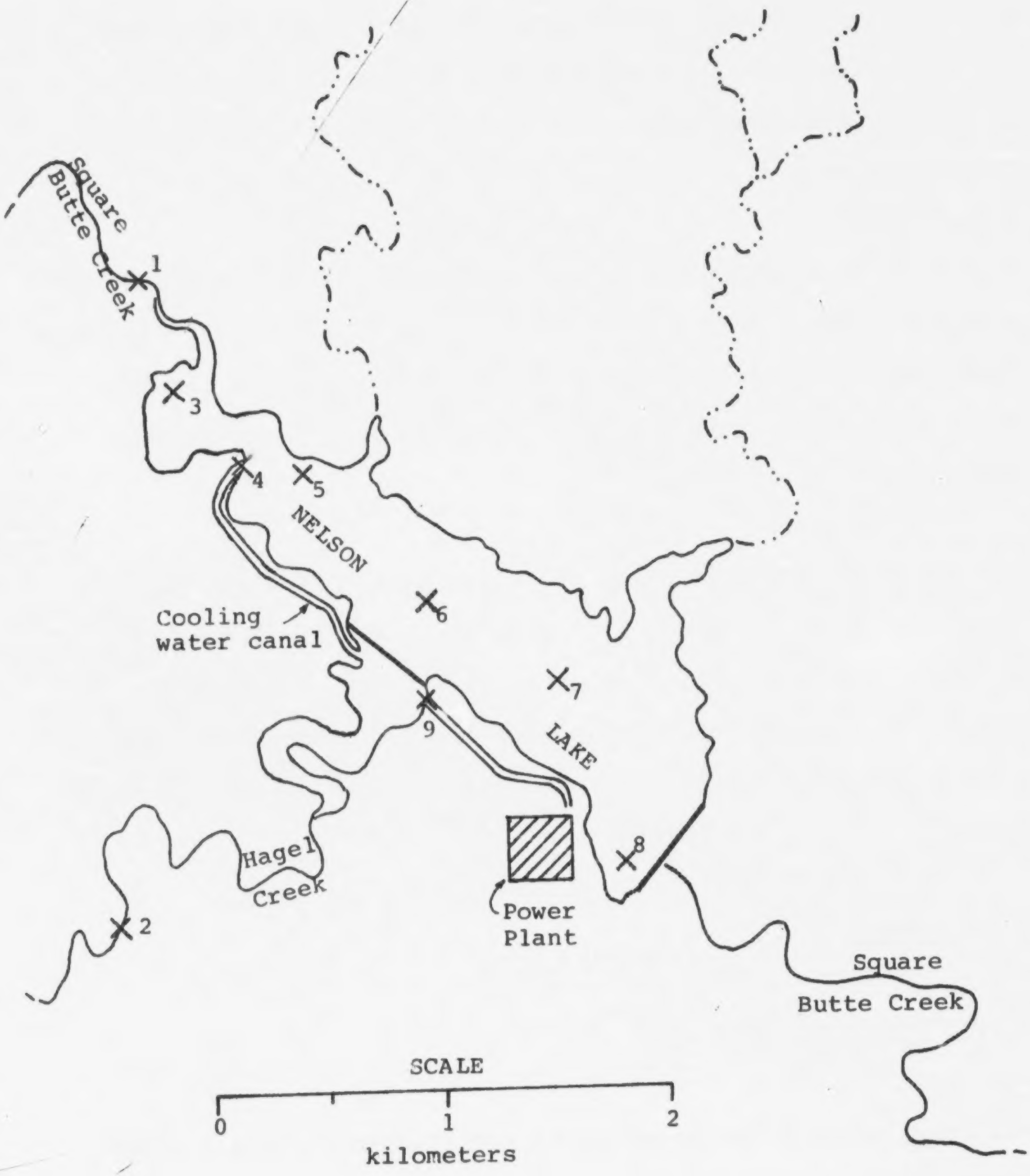

Square Butte Creek
1
3
4
5
NELSON
6
Cooling water canal
7
9
LAKE
8
Hagel Creek
2
Power Plant
Square Butte Creek
SCALE
0
1
2
kilometers

Figure 11. Map of aquatic sampling locations.

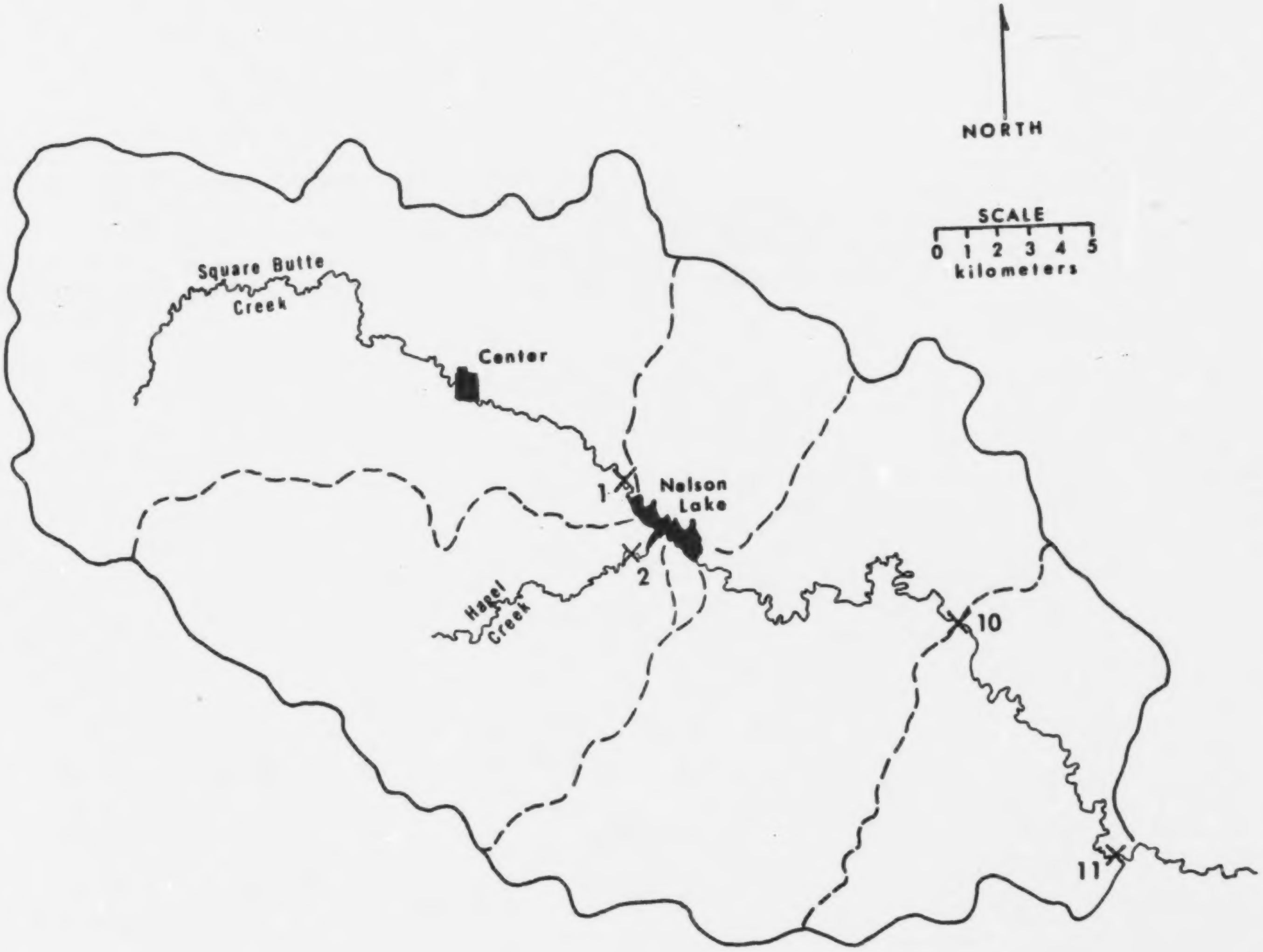

NORTH
SCALE
0 1 2 3 4 5
kilometers
Square Butte Creek
Center
Nelson Lake
1
2
Hazel Creek
10
11

Figure 12. Watershed drainage areas for stream sites 1, 2, 10, and 11.

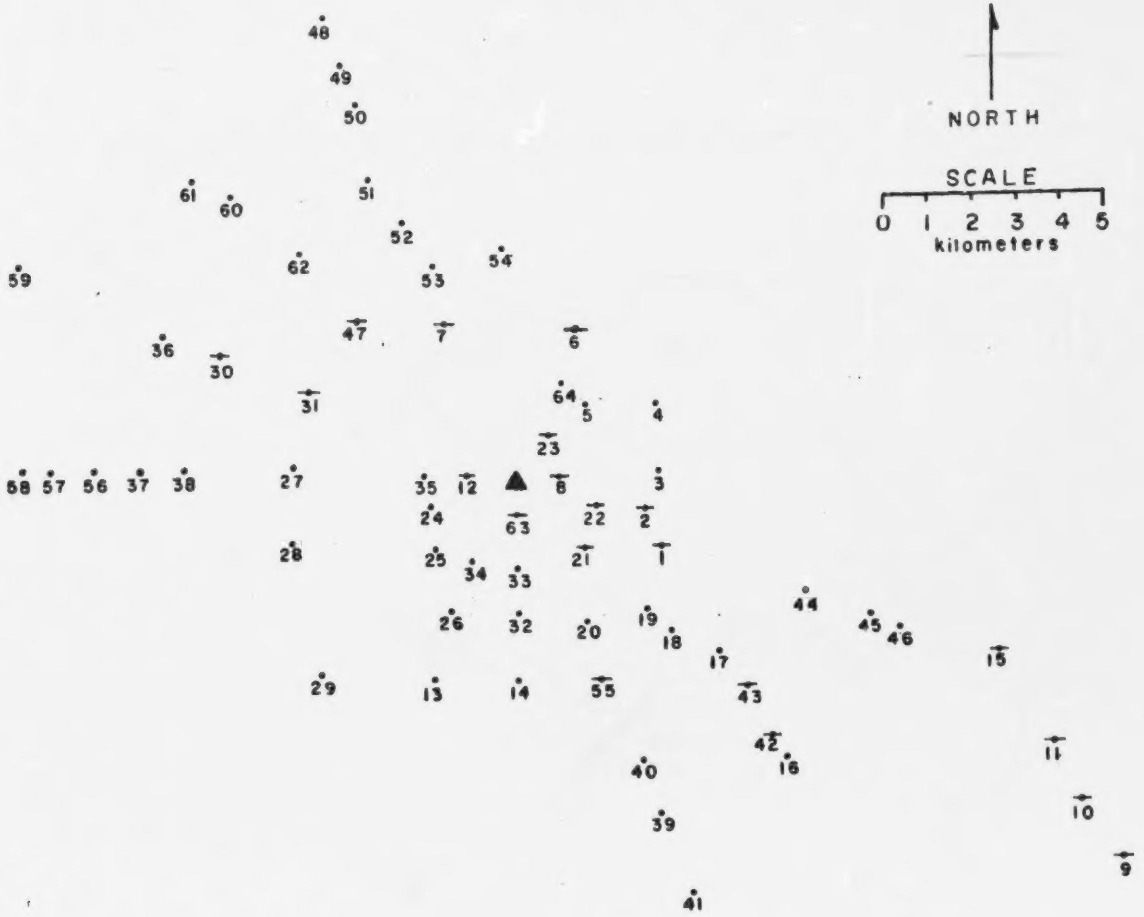

NORTH
SCALE
0 1 2 3 4 5
kilometers
48
49
50
61
60
51
52
59
62
53
54
47
7
6
36
30
31
64
5
4
23
58
57
56
37
38
27
35
12
8
3
24
63
22
2
28
25
34
33
21
1
44
26
32
20
19
18
45
46
17
15
29
13
14
55
43
42
16
11
40
10
39
9
41

Figure 13. Map of field plots at which soil samples were collected. Numbers shown were assigned plot identification numbers. The '▲' marks the location of the Milton R. Young Power Plant. A '-•-' marks plots at which both 1.3-cm and 10-cm deep samples were taken.

additional 1.3-centimeter (1.3-cm) sample of the soil surface was taken at 20 plots. Each sample was a composite of two subsamples collected 30 meters apart within the plot.

At 28 of the plots, a 91.4-centimeter soil core was taken with a hydraulic coring machine mounted on a pickup truck. These cores were used for a complete soils classification. Soil characteristics of color, texture, and structure of the surface 15 centimeters for all 64 sampling plots were identified. All sites were of undisturbed soil to reduce the influence of anthropogenic activities, namely cultivation activities and the application of fertilizers and pesticides. Slope, drainage, and land use were noted at each plot and recorded.

3.11 Vegetation

3.11.1 Sampling

A species specific approach was employed in the sampling of seven species of vegetation. The sampling was conducted at the same plots from which soil samples were collected. Table 4 lists the names of species collected, the number of samples collected, and the growth stage at the time of sample collection. Each of the vegetation species were not sampled at each plot, because specimens of the species did not grow on all plots.

Figure 14 shows a typical plot and Figures 15 through 21 are photographs of specimens of each species sampled.

TABLE 4

SPECIES OF VEGETATION SAMPLED

Species Name	Common Name	Number of Samples	Growth Stage
Agropyron smithii	Western Wheatgrass	47	Mature
Andropogon scoparius	Little Bluestem	20	Mature
Carex eleocharis	Needleleaf Sedge	33	Mature
Oxytropis lambertii	Purple Loco	33	Full Bloom
Stipa comata	Needle and Thread	48	Mature
Vicia americana	Vetch	18	Full Bloom
Koeleria cristata	June Grass	46	Anthesis[1/]
Koeleria cristata	June Grass	17	Mature[2/]

1/ Anthesis is defined as the time of blooming, which was in June during the 1978 season.

2/ The second collection of Koeleria cristata occurred in September, nearly two months after the species had reached the mature stage.

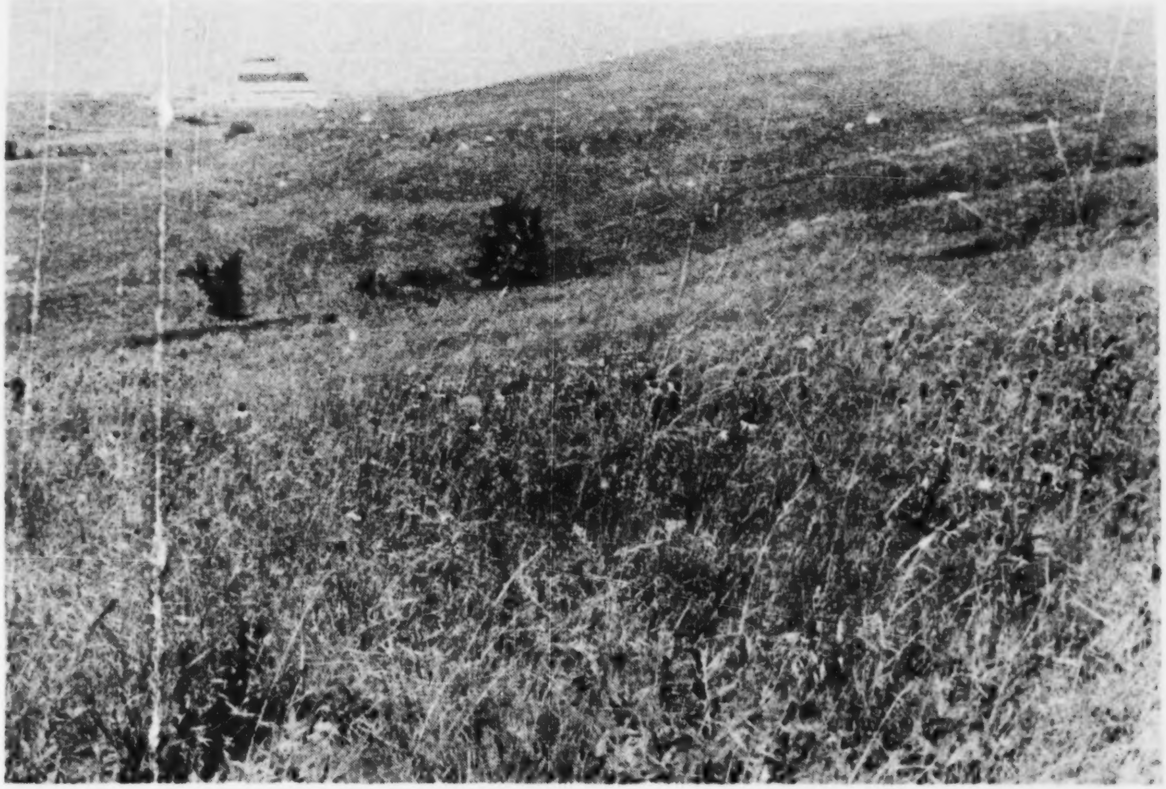


Figure 14. Photograph of a vegetation and soil sampling plot which is typical of all sampling plots.

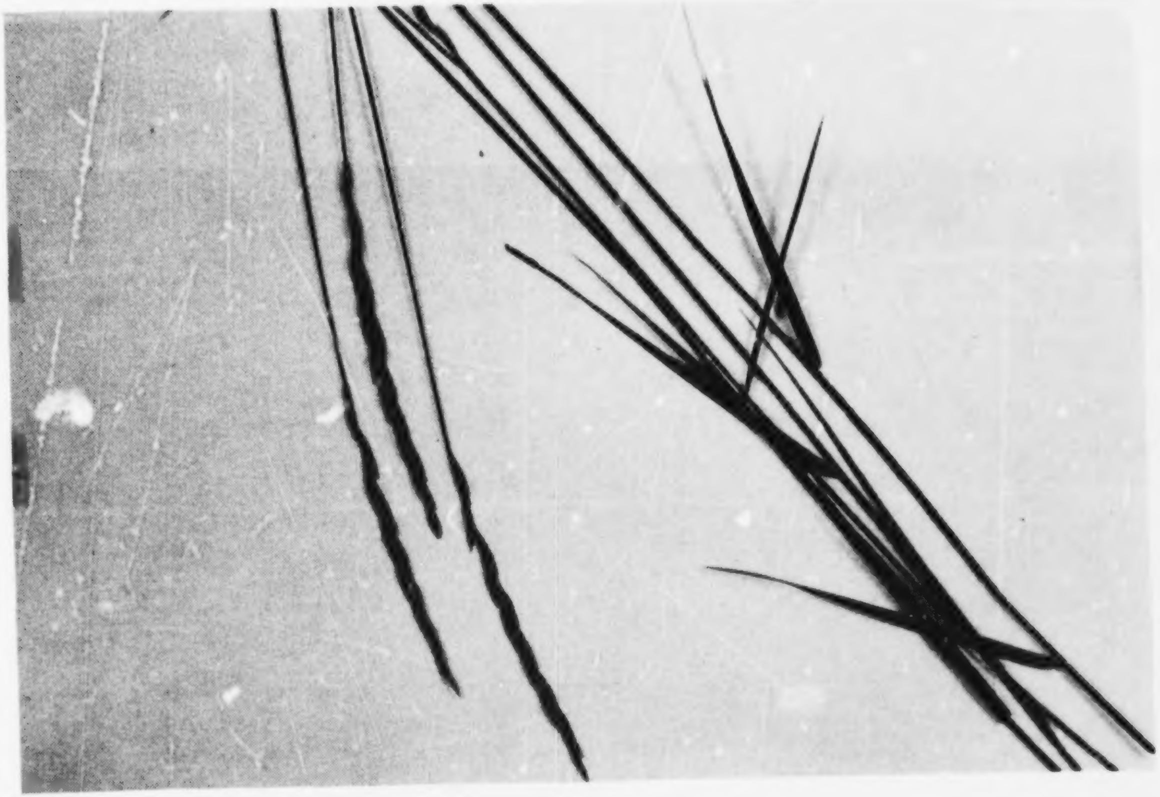


Figure 15. Photograph of the specie *Agropyron smithii*.

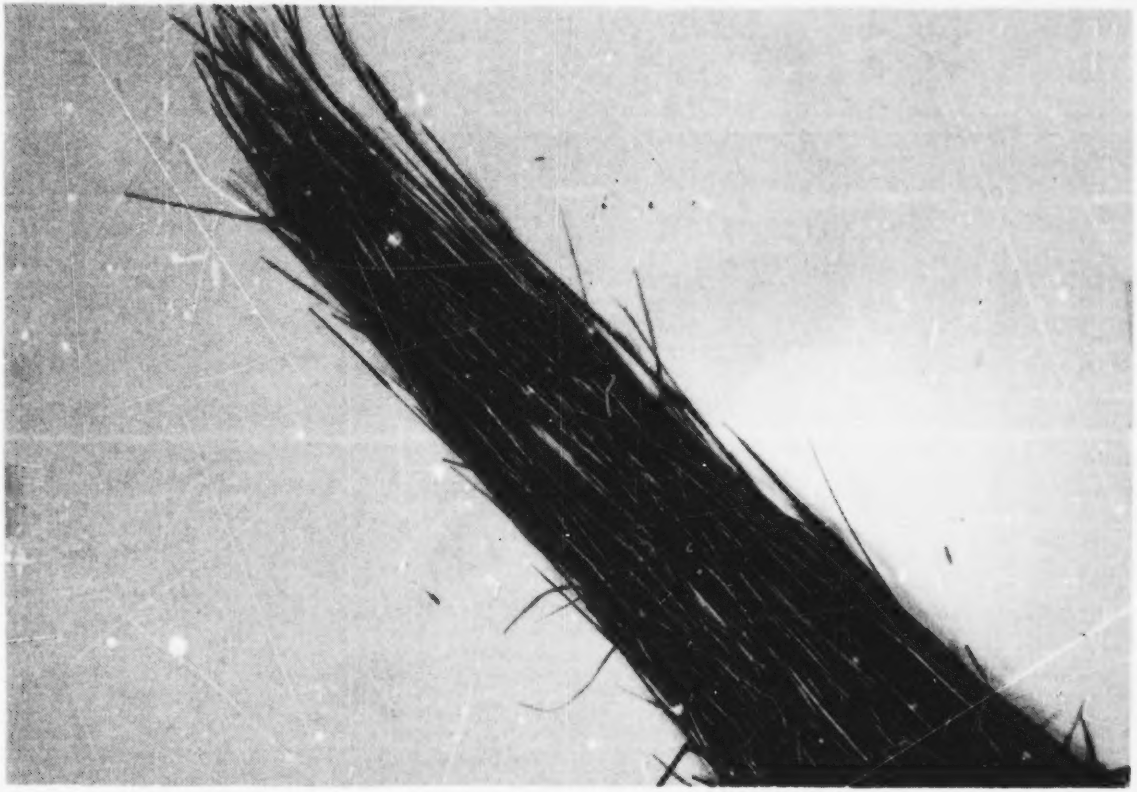


Figure 16. Photograph of the specie Andropogon scoparius.

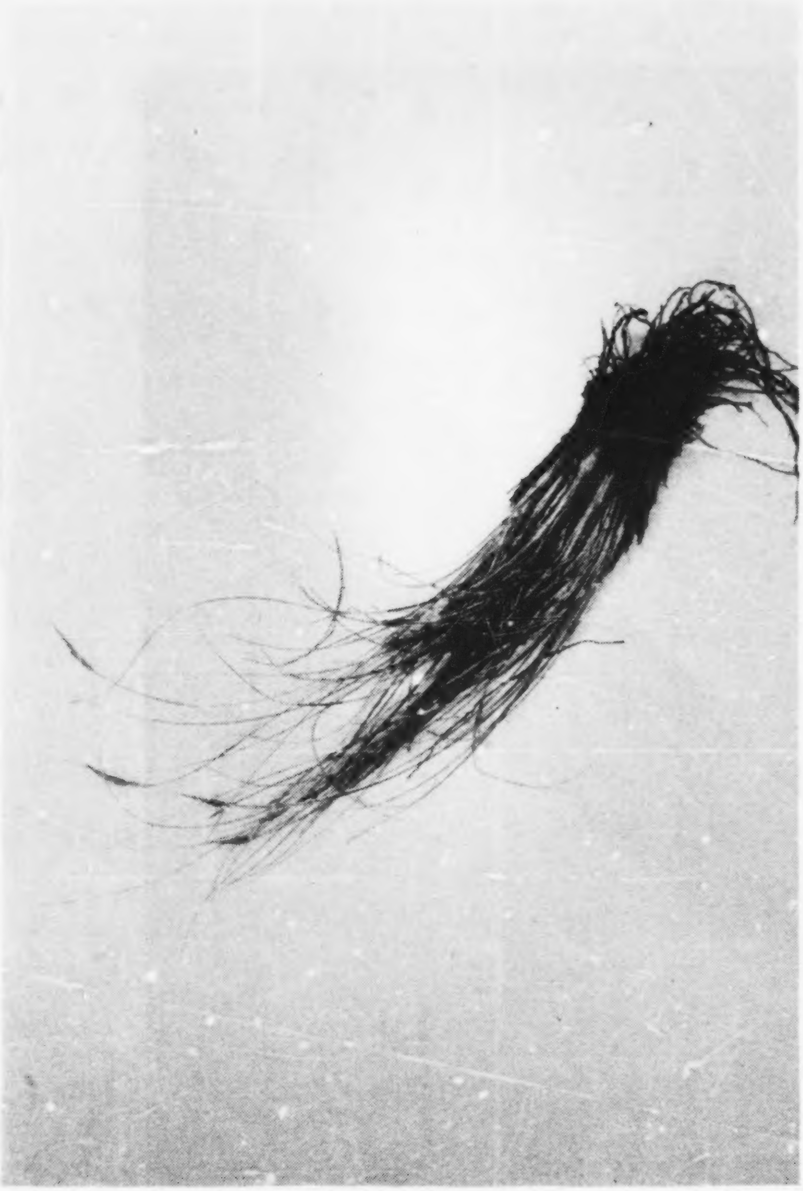


Figure 17. Photograph of the specie Carex eleocharis.

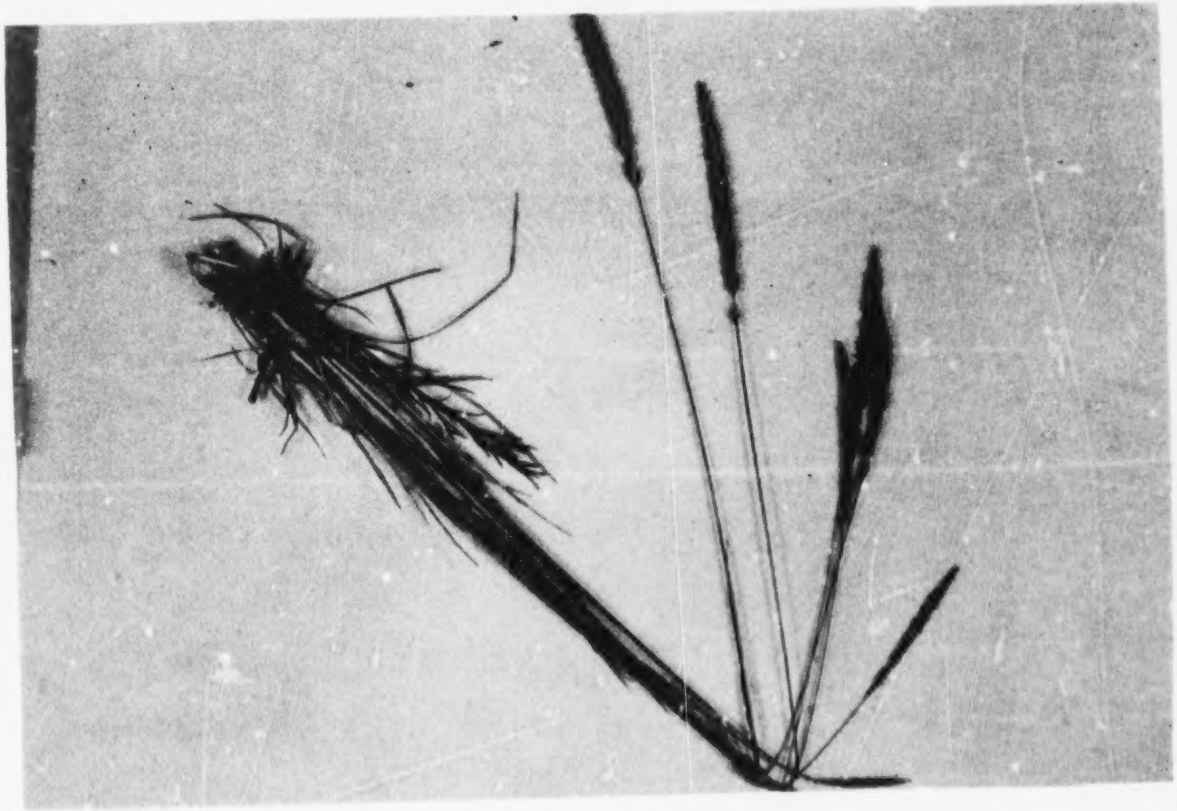


Figure 18. Photograph of the specie Koeleria cristata.

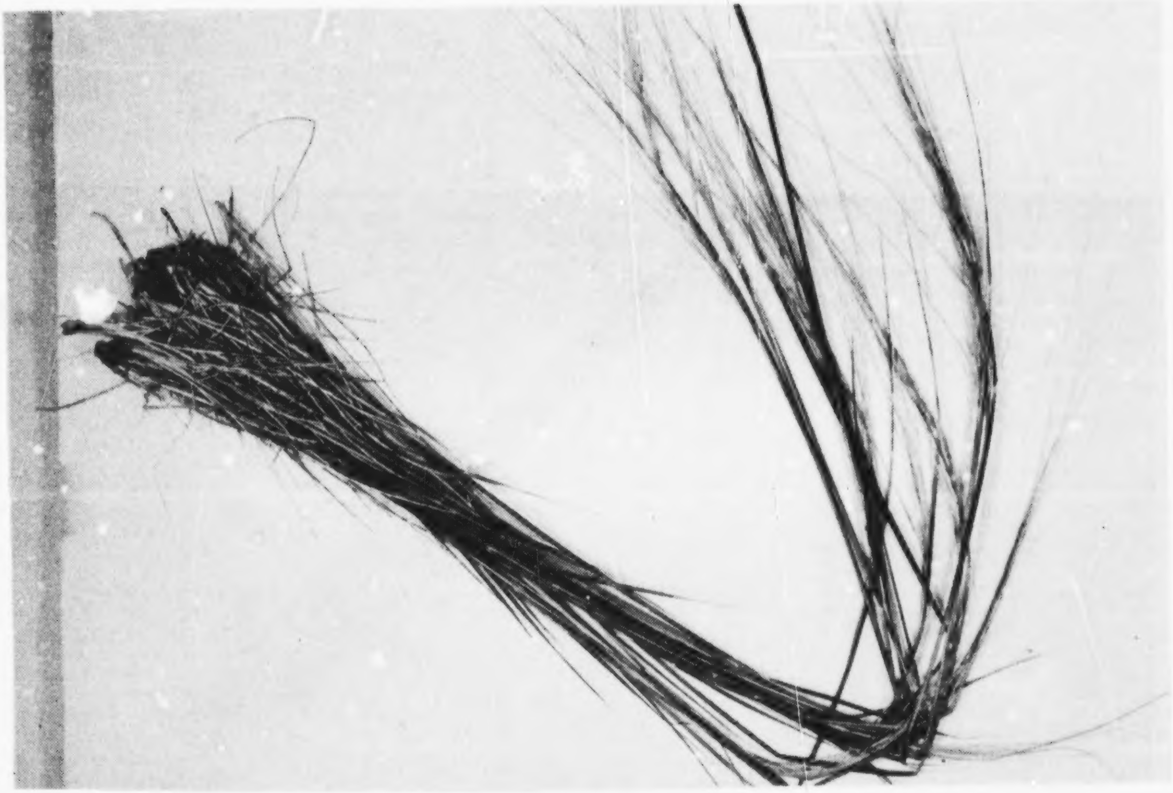


Figure 19. Photograph of the specie *Stipa comata*.

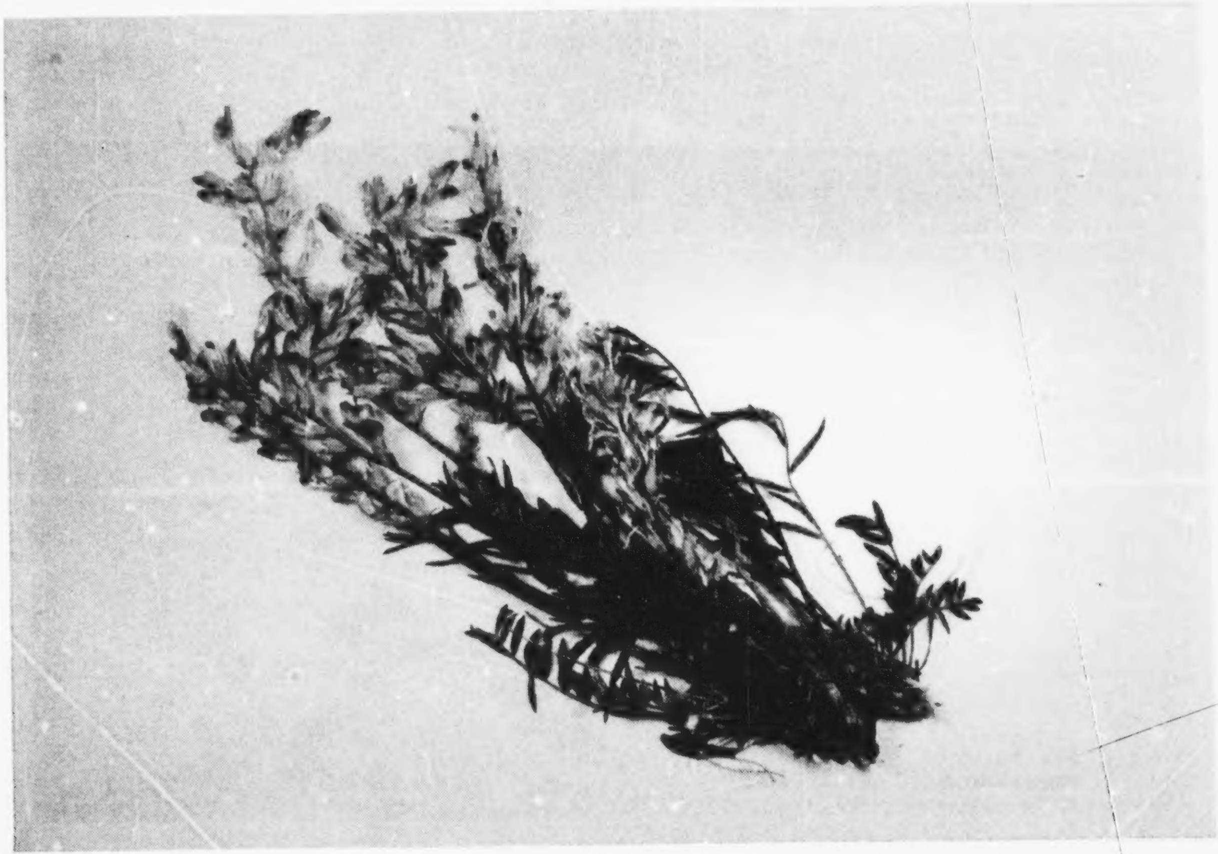


Figure 20. Photograph of the specie Oxytropis lambertii.

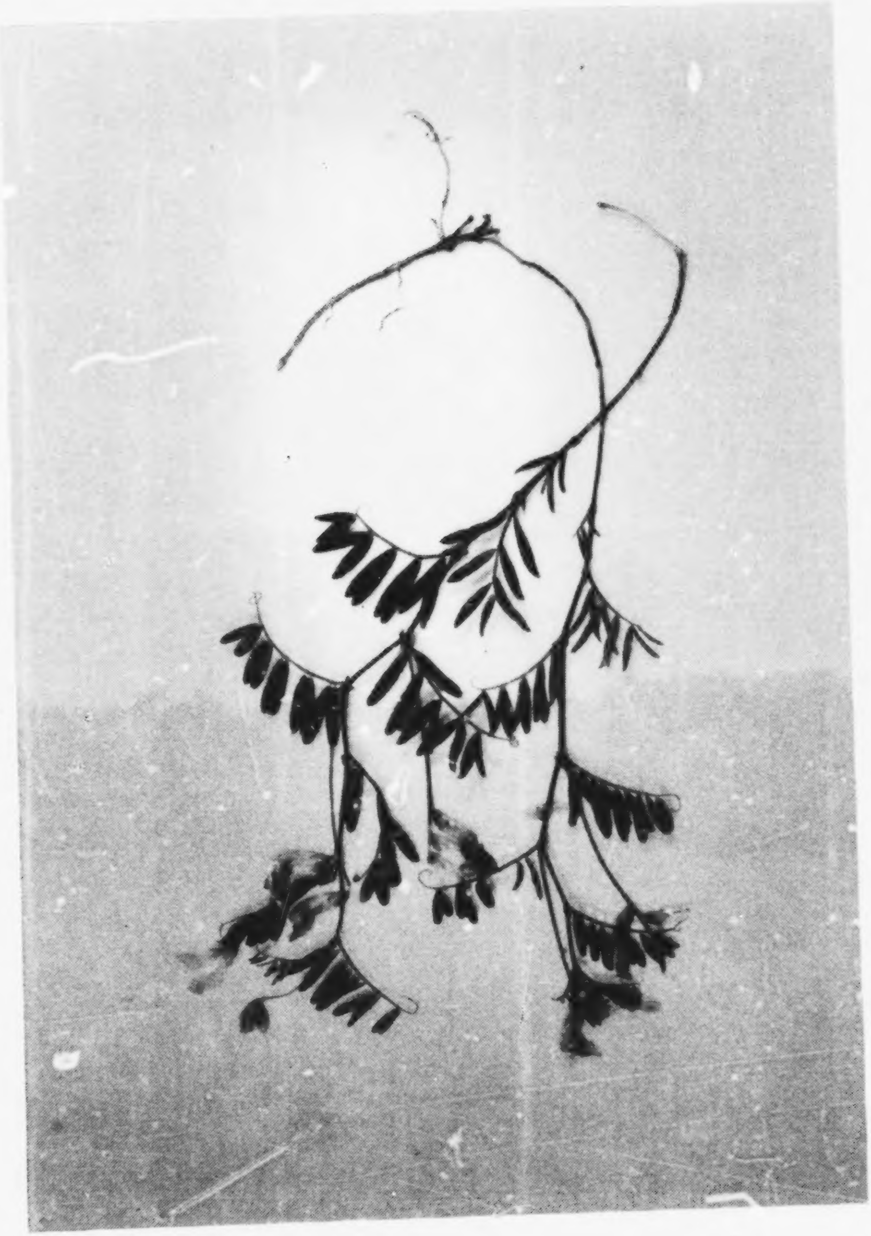


Figure 21. Photograph of the specie *Vicia americana*.

3.12 Sediment

Sediment samples were taken at all of the water sampling sites shown in Figures 11 and 12 except sites 9 and 12.

3.13 Analytical Methods

The major analytical procedures employed in this project were Instrumental Neutron Activation Analysis (INAA) and Energy Dispersive X-Ray Fluoroscence (EDXRF) for the analysis of coal, in-stack particulate, and ambient aerosol filters. Inductively Coupled Argon Plasma Spectrometer (ICAP) and Atomic Absorption Spectrometry (AAS) for soil, sediment, and vegetation; and (AAS) for water, snow, and precipitation.

4. PRESENTATION AND ANALYSIS OF DATA

An extensive quantity of data was generated during the project. Individual observations, from which statistical summaries were derived, are provided in Appendix D.

In some samples, concentrations of elements were less than minimum detectable levels (MDL) of laboratory analytical techniques. Statistical summaries and comparisons assumed that true values were one-half of the MDL for those measurements indicating concentrations less than corresponding MDLs (15).

4.1 Coal Data

4.1.1 Element Concentrations

The mean concentrations of selected elements in coal from the four mines are given in Table 5. Twelve samples were collected in sequence over a one-hour period from coal supplied from the Baukel-Noonan Center Mine. The ranges of concentrations of elements in these twelve samples are also shown in Table 5.

Mine-to-mine variations of element concentrations in the Fort Union coal region are apparent. Mean concentrations of elements in coal from the Indianhead Mine, South Beulah Mine, and Glenharold Mine are generally within the ranges of concentrations of samples from the Baukel-Noonan Center Mine. The number of samples

TABLE 5

MEAN CONCENTRATIONS (μg/g) OF ELEMENTS IN COAL FROM FOUR MINES[1/]

	Indianhead Coal Mine	South Beulah Coal Mine	Glenharold Coal Mine	Baukol-Noonan Center Coal Mine mean	range
Aluminum (Al)	8,300	8,700	9,300	8,300	7,100-9,800
Arsenic (As)	5.2	1.9	5.6	3.8	2.3-5.0
Barium (Ba)	~30	~30	~30	~30	
Bromine (Br)	<0.6	<0.6	<0.6	<0.6	
Calcium (Ca)	14,000	16,000	15,000	15,000	14,000-16,000
Cadmium (Cd)	<10	<10	<10	<10	
Copper (Cu)	7.98	3.93	8.93	6.08	4.50-8.90
Chlorine (Cl)	<600	<600	<600	<600	
Iron (Fe)	5,700	6,200	6,300	6,900	5,300-8,800
Potassium (K)	1,000	800	1,400	1,500	1,100-1,800
Magnesium (Mg)	3,900	4,300	3,600	3,800	3,200-4,600
Manganese (Mn)	30	80	30	40	20-60
Sodium (Na)	8,500	7,900	5,400	4,000	900-6,000
Nickel (Ni)	7.17	6.53	6.27	6.94	5.7-8.7
Phosphorus (P)	<50	<50	<50	<50	
Lead (Pb)	<5	<5	<5	<5	
Rubidium (Rb)	15.9	16.2	15.5	15.6	14-18
Sulfur (S)	8,200	9,500	11,300	8,500	6,800-11,000
Selenium (Se)	<1	<1	<1	<1	
Silicon (Si)	11,500	8,900	18,700	15,200	12,000-21,600
Strontium (Sr)	~500	~500	~500	~500	
Titanium (Ti)	530	640	430	380	320-480
Zinc (Zn)	4.7	1.8	8.2	8.0	2.1-24

1/ Concentrations are based on dry weight of coal.

obtained from each mine was inadequate to statistically evaluate significance of mine-to-mine variations.

4.2 Stack Sampling Data

The fate of trace elements contained in bulk coal, which is burned in the boiler of a coal-fired power plant, involves an extremely complex physical process. The process depends on the operating temperature of the boiler, the volatility of the element, the recondensation of the element in the air waste stream, and the air emission control system.

Two samples of flue gas emitted from Unit II of the study facility were obtained for analysis of element concentrations and calculation of emission rates.

4.2.1 Limitations of Data Set

Samples of flue gas emitted from Unit I of the study facility were not obtained. The configuration of the sampling port and limited work space on the sampling platform provided unsuitable sampling conditions.

Fly ash particles are collected as spots on the filters beneath jet holes of stage plates in the cascade inertial impactor. The mass of the spots was not large enough for the XRF analysis; thus, the concentrations of calcium, copper, nickel, sulfur, and lead were not obtained.

4.2.2 Stack Testing Conditions

A summary of stack and sampling conditions for each of the two samples is presented in Table 6.

4.2.3 Mass Size Distribution

The sampler contained seven stage plates for separation of particles by size. The aerodynamic diameter for each of the stage plates was calculated by the formula:

$$D_{50} = \sqrt{\frac{18\mu\Psi N\pi D_j^{\,3}}{4C\rho Q}}$$

$$C = 1 + \frac{2\lambda}{D_{50}} [1.23 + 0.41 \, e^{-0.44 \, D_{50}/\lambda}]$$

$$\lambda = 1.7 \times 10^{-7} \frac{T}{P}$$

where D_{50} = aerodynamic diameter, μ = air viscosity, N = number of jets in stage plate, D_j = jet diameter, ρ = particle density $\equiv$ 1 gram per cubic centimeter, Q = actual flow rate, Ψ = dimensionless inertial impaction parameter $\equiv$ 0.14, C = Cunningham slip correction factor, and T and P are absolute temperature and pressure, respectively, at sampling conditions.

The aerodynamic diameter and net mass loading on each stage substrate for each sample are provided in Table 7. Cumulative particle mass distributions for each sample are plotted in Figure 22.

TABLE 6

STACK SAMPLING CONDITIONS

Condition	Run #1	Run #2
Coal feed rate (kg/min)	5,626	5,431
Ambient atmospheric pressure (meters Hg)	0.694	0.693
Stack static pressure (meters Hg)	0.692	0.690
Stack gas temperature (Centigrade)	129	124
Sample time (minutes)	80	100
Stack gas velocity (meter/second)	20.7	20.8
Average dry gas volume flow (liter/minute)	13.7	14.8
Temperature of dry gas meter (Centigrade)	32.2	35.6
Volume of condensate (milliliters)	184.9	189.9
Temperature of sampler box (Centigrade)	8.9	4.4
Isokineticity (percent)	110.1	103.3
Total volume sampled at stack conditions (cubic meter)	2.18	2.31

TABLE 7

AERODYNAMIC DIAMETER AND MASS LOADING OF EACH STAGE PLATE

	Run #1		Run #2	
Stage	D_{50} (micrometers)	Mass Loading (milligrams)	D_{50} (micrometers)	Mass Loading (milligrams)
1	23.4	0.1	25.9	0.1
2	10.2	0.1	11.3	0.1
3	3.80	0.5	4.22	0.3
4	1.89	1.1	2.10	0.9
5	1.03	1.0	1.16	1.1
6	0.52	0.4	0.59	0.5
7	0.26	0.4	0.30	0.3
FF[1]		0.2		0.2

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[1] FF is final filter.

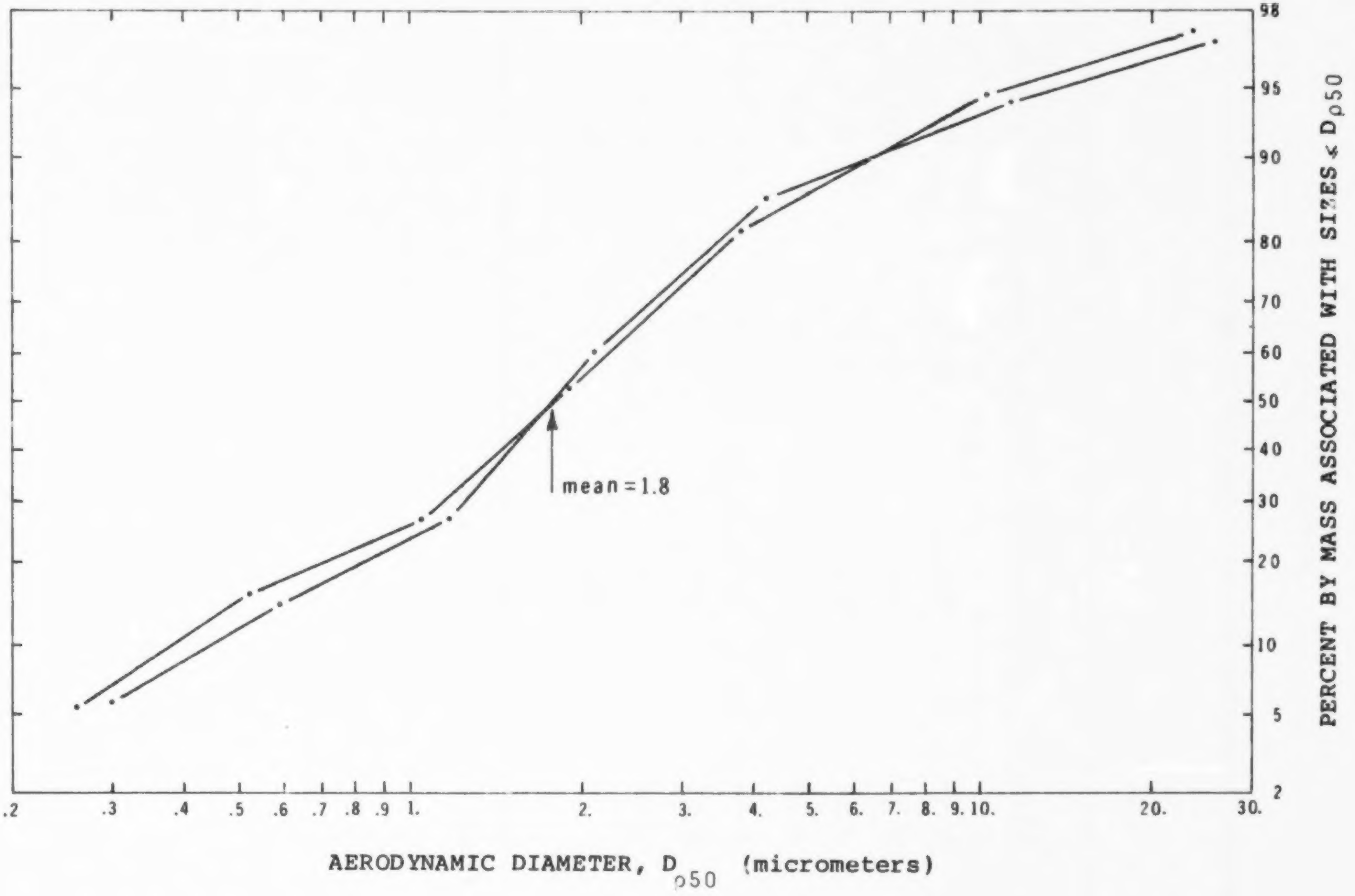

Figure 22. Cumulative mass distribution of stack fly ash.

Since the emission control system, an electrostatic precipitator, was designed to remove about 99 percent of the particles greater than 10-micrometers diameter, the low mass loading on stages 1 and 2 was not unexpected. The mean mass particle diameter of particulate contained in the stack exhaust gas was 1.8 micrometers.

4.2.4 Particulate Element Concentrations

Concentrations of certain elements in fly ash were analyzed for each stage filter of both sample runs. These concentrations are listed in Tables 8 and 9.

The data suggest a particle size dependent concentration for certain elements.

1) Aluminum concentrations decrease with decreasing particle size.

2) Magnesium concentrations are bimodal with larger concentrations for stages 1 and 6 or particle sizes of about 24 and 0.5 micrometers, respectively.

3) Potassium and vanadium concentrations increase for the final filter (FF) or a particle size of about 0.3 micrometers.

TABLE 8

ELEMENT CONCENTRATIONS (μg/g) IN FLY ASH BY IMPACTOR STAGE FOR RUN #1

	Impactor Stage							
Element	FF	7	6	5	4	3	2	1
Aluminum	19,500	32,000	75,250	77,300	86,550	98,200	101,000	91,000
Iron	113,500	77,500	70,600	78,830	89,337	88,600	170,240	100,200
Magnesium	31,000	35,500	58,750	41,200	39,730	44,200	62,000	63,000
Sodium	29,500	19,750	21,000	15,000	16,640	19,000	27,000	27,000
Potassium	46,000	17,500	16,500	15,000	14,900	11,800	19,000	50,000
Chromium	1,880	840	980	580	1,710	630	3,680	2,400
Titanium	2,500	2,750	6,500	4,800	5,730	5,800	4,300	<3,800
Zinc	-[1]	410	710	580	1,320	1,670	2,380	2,570
Manganese	1,050	830	1,200	1,020	1,140	1,280	1,500	1,700
Vanadium	1,800	1,000	850	610	550	600	700	480
Arsenic	800	650	680	880	800	820	970	410
Antimony	95	88	113	120	91	80	140	70
Lanthanum	1,820	53	60	51	84	84	1,000	120
Selenium	600	-	-	-	-	-	-	-
Bromine	110	78	45	31	35	58	770	60
Cobalt	60	28	55	32	35	38	100	70
Samarium	10	8	10	8	7	8	10	10
Scandium	+[2]	10	23	21	21	20	30	20
Hafnium	+	8	18	11	<8	+	80	<60
Tantalum	<15	35	<8	12	<18	+	+	+
Europium	5	8	8	6	5	8	30	20
Thorium	+	13	30	18	16	<12	+	40

[1] A '-' indicates concentration was less than blank filter analysis.
[2] A '+' indicates concentration was less than 0.000 micrograms per filter.

TABLE 9

ELEMENT CONCENTRATIONS (μg/g) IN FLY ASH BY IMPACTOR STAGE FOR RUN #2

	Impactor Stage							
Element	FF	7	6	5	4	3	2	1
Aluminum	<18,000	30,700	76,400	75,600	80,700	125,700	78,000	91,000
Iron	72,500	97,100		71,100	80,200	105,600	203,600	138,100
Magnesium	30,000	39,300	61,800	43,700	39,700	57,000	40,000	66,000
Sodium	26,000	22,300	23,600	14,360	16,400	24,700	20,000	24,000
Potassium	21,500	19,000	<1,200	9,100	7,800	24,000	<7,700	29,000
Chromium	4,960	4,090		540	2,230	730	26,100	13,300
Titanium	<3,350	2,400	5,000	4,460	4,220	7,000	<4,300	<4,000
Zinc	-1/	1,270		900	940	1,760	2,360	-
Manganese	1,050	930	1,280	1,040	1,170	1,570	3,700	2,400
Vanadium	1,500	1,700	820	510	478	733	630	660
Arsenic	455	600		640	800	933	1,100	680
Antimony	80	73		79	90	123	100	100
Lanthanum	140	37		44	48	80	490	90
Selenium	620	-		-	-	-	-	-
Bromine	208	57	222	52	47	70	610	160
Cobalt	15	80		86	43	33	280	310
Samarium	5	10		6	7	10	10	10
Scandium	+2/	10		17	19	19	30	30
Hafnium	<30	+		+	13	<23	50	<60
Tantalum	<15	+		56	9	80	30	<30
Europium	5			6	7	10	40	40
Thorium	<30	30		20	21	<20	+	40

1/ A '-' indicates concentration was less than blank filter analysis.
2/ A '+' indicates concentration was less than 0.000 micrograms per filter.

4) Titanium concentrations are larger for stages 3, 4, 5 and 6 or particle sizes of about 4, 2, 1, and 0.5 micrometers, respectively.

5) Bromine and lanthanum concentrations are larger for stages 2 and FF or particle sizes of about 10 and 0.3 micrometers, respectively.

Mass loadings for stages 1 and 2 were at levels of sensitivity of the balance available for weighing the filters. The mass loading shown in Table 7 error by being larger than true values for stages 1 and 2. The effect on concentrations given in Tables 8 and 9 is to bias the concentrations lower than true values.

4.2.5 Element Emissions

The concentrations of certain elements in coal consumed by the study facility during the sampling runs are listed in Table 10. The input rates (micrograms per second, μg/sec) of certain elements in the feed coal for sample run #1 and sample run #2 are given in Tables 11 and 12, respectively.

The output rates of elements contained in the flue gas as fly ash and as gaseous particles are also shown in Tables 11 and 12.

TABLE 10

ELEMENT CONCENTRATIONS (μg/g) IN COAL WHICH WERE CONSUMED DURING SAMPLING OF STACK FLUE GAS

Element	Run #1	Run #2
Aluminum	12,000	11,000
Arsenic	3.5	3.0
Barium	~30	~30
Bromine	<1	<1
Calcium	16,000	15,000
Cadmium	<10	<10
Copper	7	13
Chlorine	<600	<600
Iron	7,400	6,500
Potassium	1,900	1,500
Magnesium	3,600	3,600
Manganese	70	60
Sodium	1,900	2,000
Nickel	6.5	8.0
Phosphorus	<50	<50
Lead	<5	<5
Rubidium	17	18
Sulfur	10,000	10,000
Selenium	<1	<1
Silicon	20,000	16,000
Strontium	~500	~500
Titanium	600	600
Zinc	10	10

TABLE 11

FRACTIONS OF ELEMENTS IN FLUE GAS RELATIVE TO COAL INPUT FOR RUN #1

Element	Coal Input (μg/sec)	Output (μg/sec)	Fraction (percent)
Impactor Collection:			
Arsenic	2.14×10^{5}	1.25×10^{3}	0.584
Aluminum	7.32×10^{8}	1.24×10^{5}	0.0169
Chlorine	1.83×10^{7}	1.38×10^{3}	0.0075
Chromium[1]	4.69×10^{5}	3.67×10^{3}	0.783
Potassium	1.16×10^{8}	2.89×10^{4}	0.0249
Magnesium	2.20×10^{8}	7.04×10^{4}	0.0320
Manganese	4.27×10^{6}	1.83×10^{3}	0.0429
Sodium	1.16×10^{8}	3.03×10^{4}	0.0261
Selenium[2]	3.75×10^{4}	5.07×10^{1}	0.135
Titanium	3.66×10^{7}	8.10×10^{3}	0.0221
Zinc	9.38×10^{5}	1.64×10^{3}	0.175
Impingers Collection:			
Arsenic	2.14×10^{5}	5.69×10^{3}	2.66
Cadmium	3.05×10^{5}	3.66×10^{2}	0.120
Copper	4.27×10^{5}	1.05×10^{4}	2.46
Lead	1.53×10^{5}	1.72×10^{4}	11.2
Selenium			
Mercury	1.22×10^{4}	7.15×10^{2}	5.86

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[1] Assumed coal concentration of 5 micrograms per gram.

[2] Assumed coal concentration of 0.5 micrograms per gram.

TABLE 12

FRACTIONS OF ELEMENTS IN FLUE GAS RELATIVE TO COAL INPUT FOR RUN #2

Element	Coal Input (μg/sec)	Output (μg/sec)	Fraction (percent)
Impactor Collection:			
Aluminum	6.47×10^8	1.06×10^5	0.0164
Chlorine	1.77×10^7	1.31×10^3	0.0074
Chromium1/	4.53×10^5	1.93×10^3	0.426
Potassium	8.83×10^7	1.75×10^4	0.0198
Magnesium	2.12×10^8	6.55×10^4	0.0309
Manganese	3.53×10^6	1.80×10^3	0.0510
Sodium	1.18×10^8	2.70×10^4	0.0229
Selenium2/	3.62×10^4	5.17×10^1	0.143
Titanium	3.53×10^7	6.14×10^3	0.0174
Zinc	9.05×10^5	1.21×10^3	0.133
Impingers Collection:			
Arsenic	1.77×10^5	4.16×10^3	2.35
Cadmium	2.94×10^5	1.14×10^3	0.388
Copper	7.65×10^5	8.36×10^3	1.09
Lead	1.47×10^5	1.82×10^4	12.4
Selenium	1.18×10^4	2.49×10^3	21.1
Mercury	1.18×10^4	2.13×10^2	1.81

1/ Assumed coal concentration of 5 micrograms per gram.
2/ Assumed coal concentration of 0.5 micrograms per gram.

Since the precipitator and the wet scrubber remove a large portion of the fly ash produced by the boiler, the output rates are less than the input rates. The fractions of elements in feed coal which are emitted in the flue gas waste stream are shown in Tables 11 and 12.

Spike recovery analysis of the impinger solutions was inconsistent for arsenic, cadmium, copper, lead, and selenium. Mercury spike recovery analysis was consistent at a level of about 80 percent.

4.3 Computer Modeling Data

4.3.1 Limitation of Analysis

The modeling analysis described below is based upon climatological data for surface temperature, stability, wind speed, wind direction, rainfall rate, and rainfall duration. This data is sufficient for computer modeling of "average" seasonal and annual conditions, but it may not adequately represent meteorological conditions during the 1978 field sampling period.

4.3.2 Element Emission Rates

One of several input parameters to the computer model (ATDM) is the emission rate of the element within the stack flue gas. The emission rates (output) can be obtained directly from Tables 11 and 12. However, the output of elements shown in these tables are less than outputs indicated by other studies. Additional stack sampling of the study facility should be concluded before the data in Tables 11 and 12 are accepted as representative of facilities such as the study facility.

The emission rates of elements were determined with the following equation:

$$G_n = CFR \times (1 - WL) \times TEC \times F$$

G_n is the emission rate in units of grams per second, CFR is the coal feed rate in units of grams per second, WL is the water loading which was taken as 0.35, TEC is the element concentration in coal in units of grams per gram, and F is the fraction of the element contained in coal which is emitted with the stack flue gas. Values for F were obtained from Table 57 shown in Section 5.2.

4.3.3 Predicted Impact of Study Facility

The ATDM computer model was used to predict the average seasonal contribution of zinc to the aerosol concentration by the plume of the study facility. The average seaonal (April 1 through August 31) ground-level air concentration resulting from plume diffusion is shown in Figure 23.

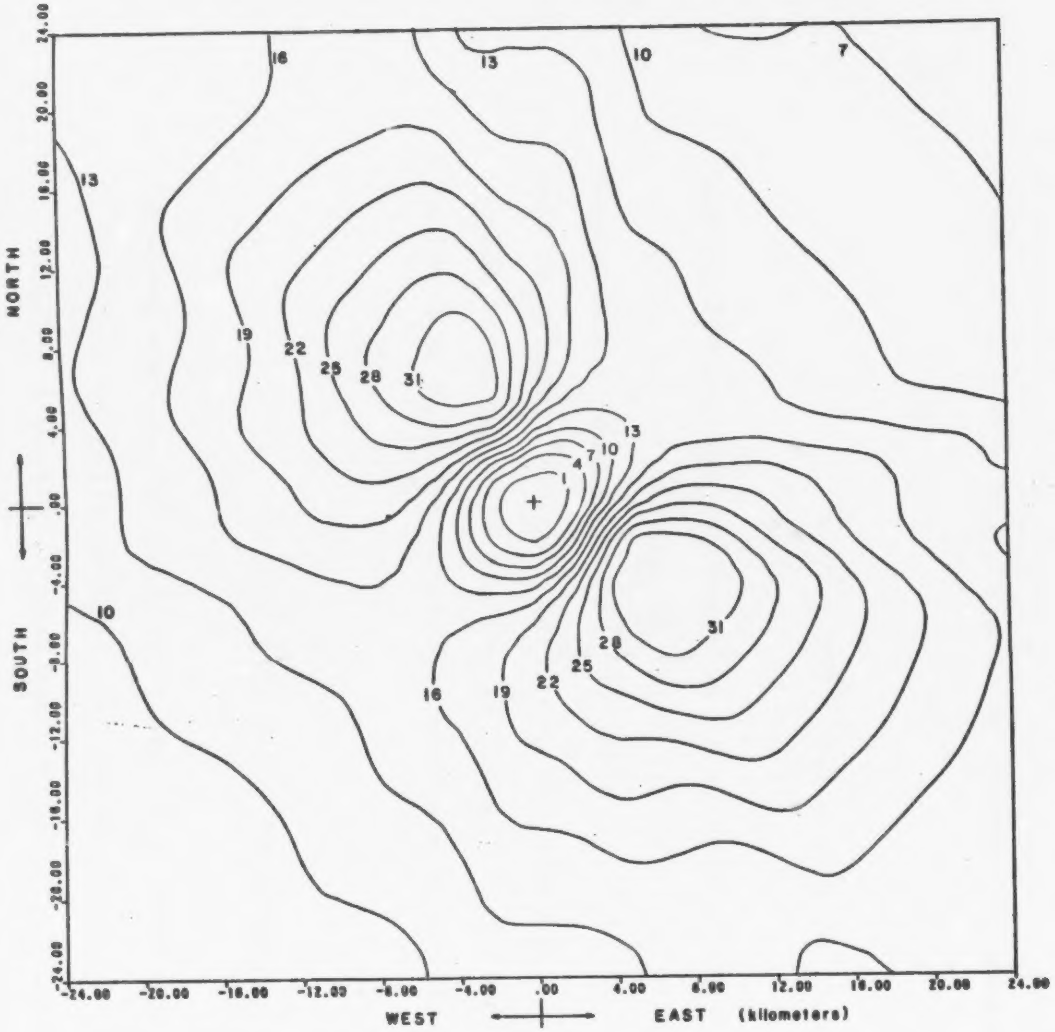
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Figure 23. Pattern of average growing season ground-level air concentrations (picograms per cubic meter) from the plume of the study facility.

Ground-level air concentrations of zinc in the plume of the study facility, as predicted by ATDM, over the study area range from 13 to 33 picograms (10^{-12} grams per gram) per cubic meter of air. Higher concentrations occur northwest and southeast of the study facility due to more frequent occurrence of winds with these directions.

The annual rate of atmospheric deposition of zinc predicted by ATDM is shown in Figure 24. The average annual rate at which zinc is deposited on the soil surface, as predicted by the computer model, ranges from 0.1 to 8 picograms per square meter per second. Conversely, the annual deposition ranges from 0.00032 to 0.025 micrograms per square centimeter. The largest amount of deposition is predicted to occur in the vicinity of the study facility.

4.3.4 Predicted Impact of Sources Surrounding Study Area

Element emissions for coal-fired sources adjacent to the study area were also determined by the procedure in Section 4.3.2 above with data from Tables 3, 5, and 57.

The predicted pattern of average seasonal, April through August, ground-level air concentrations of zinc resulting from plumes of the four coal-fired facilities adjacent to the study area is shown in Figure 25. Concentrations in the study area resulting from these facilities range from 12 to 30 picograms per cubic meter.

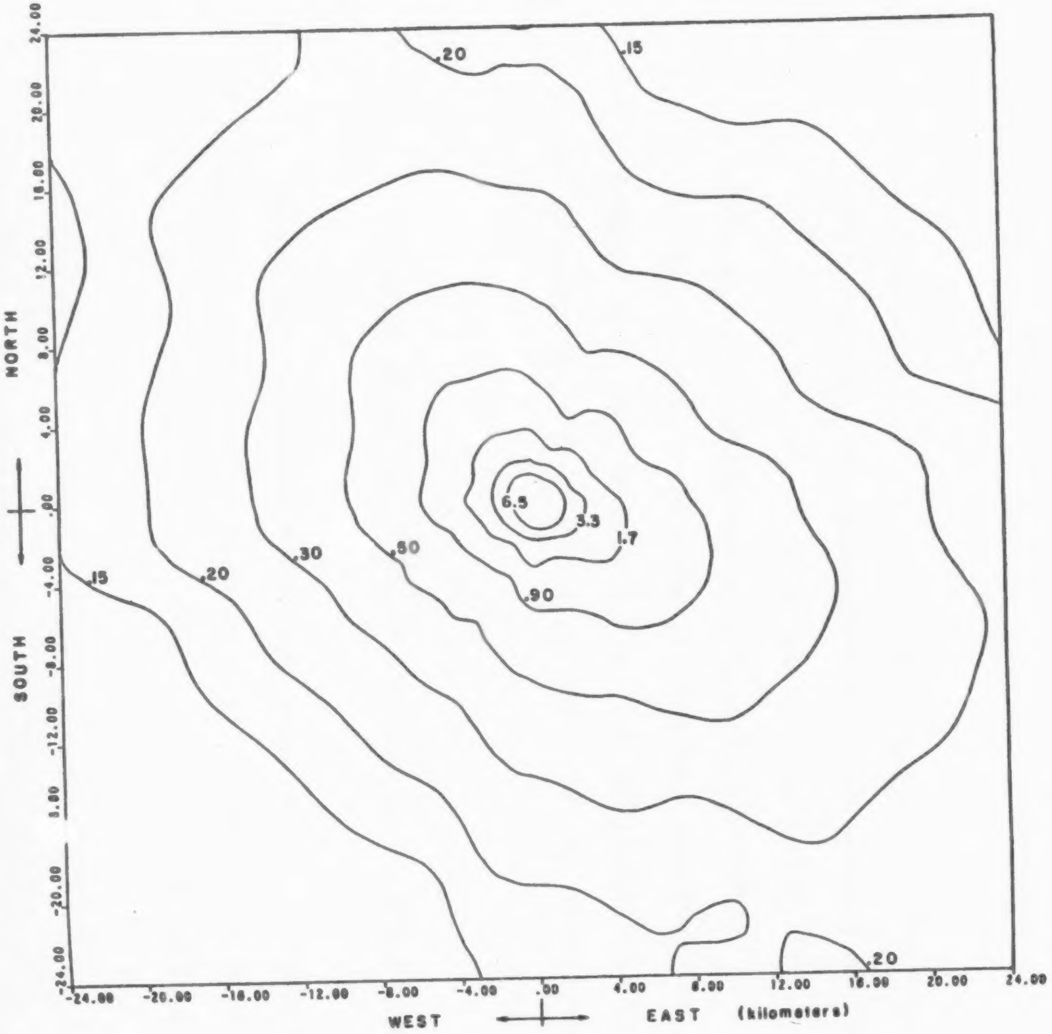
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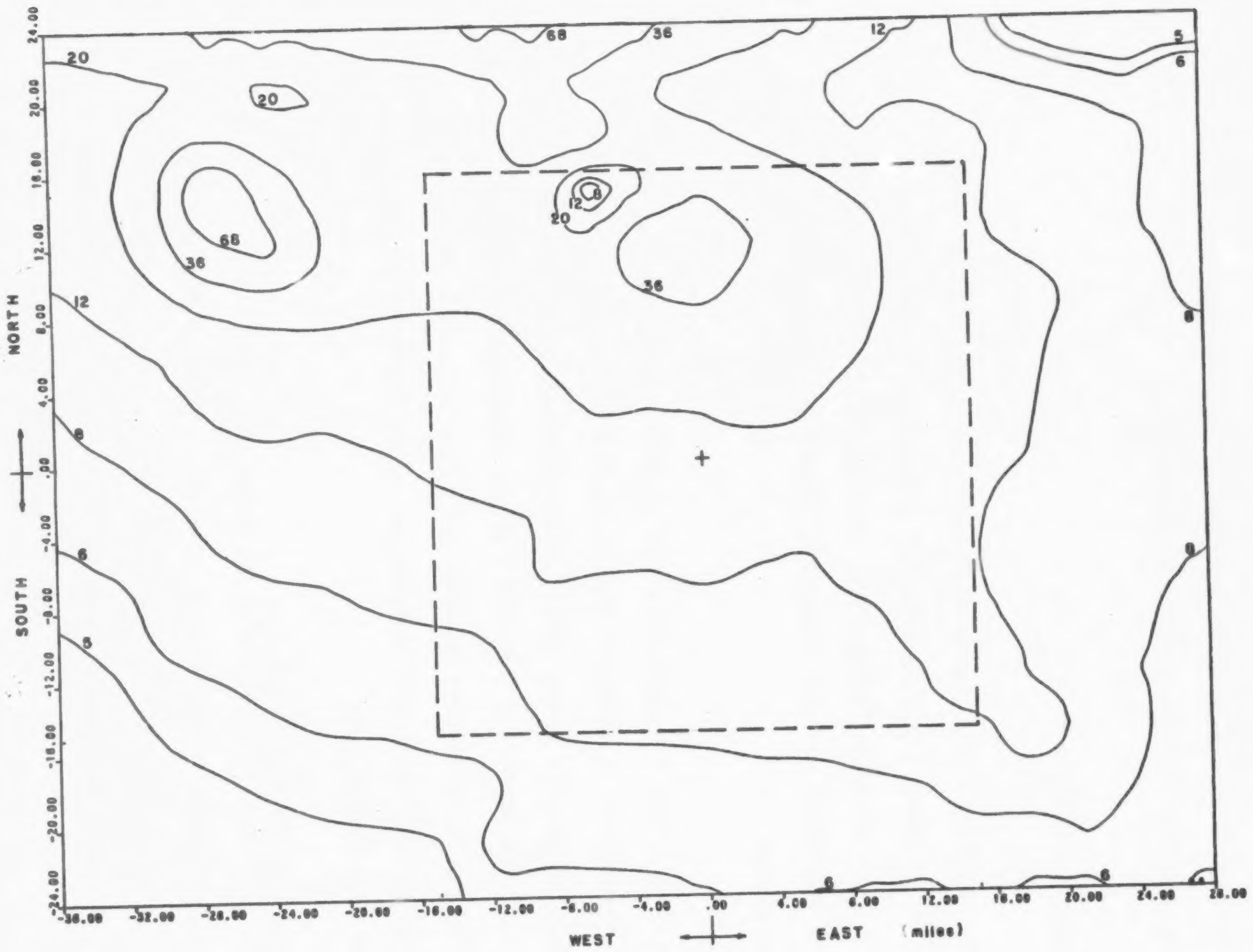
Figure 24. Pattern of the annual rate of zinc deposition (picograms per square meter per second) from the plume of the study facility.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20
12
8
36

Figure 25. Pattern of predicted average seasonal contribution to ground-level air concentrations (picograms per cubic meter) of zinc from coal-fired sources adjacent to the study area.

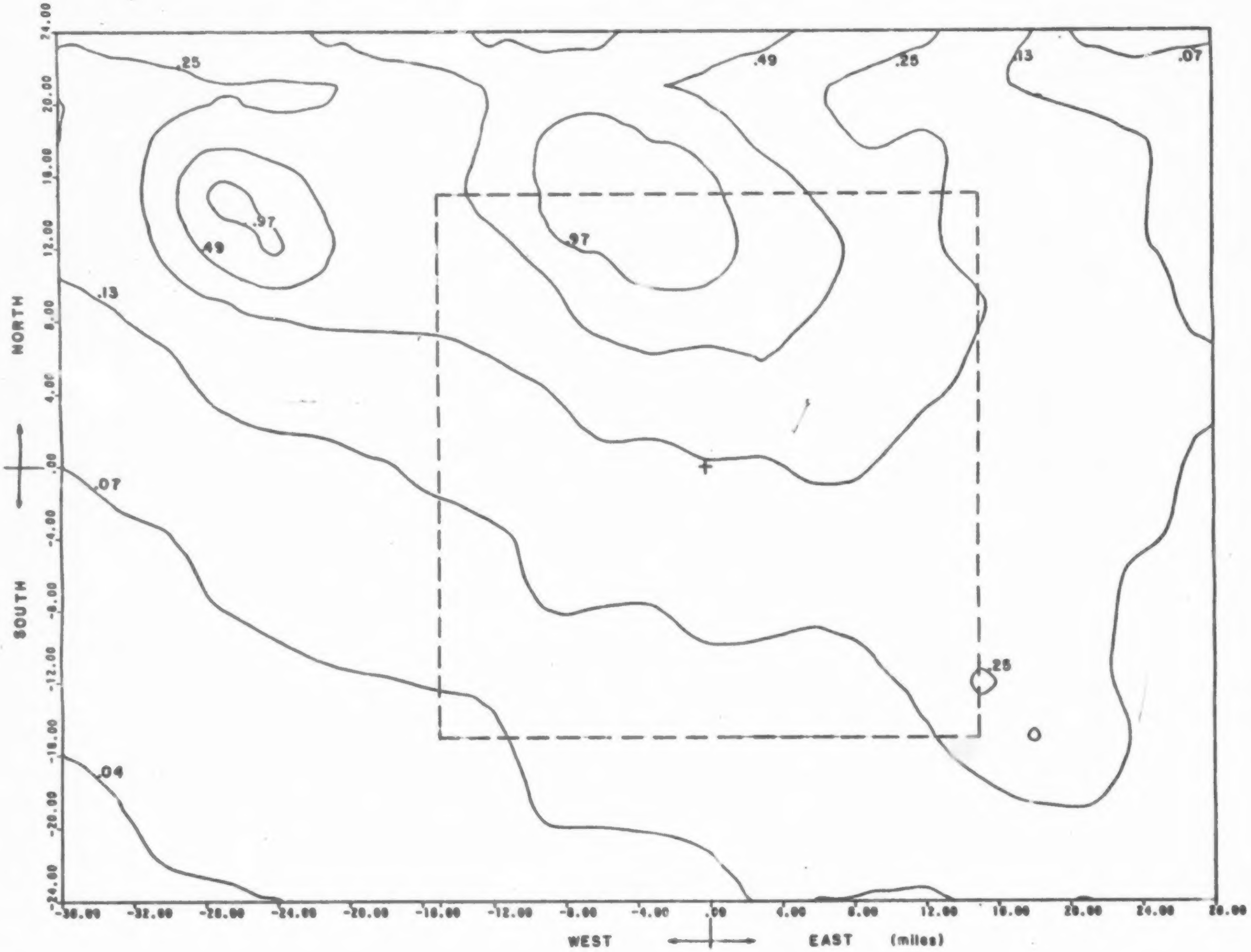
The pattern of the annual rate of deposition of zinc from the four facilities is shown in Figure 26. The annual rates of deposition in the study area from the facilities ranges from 0.13 to 0.49 picograms per square meter per second.

4.3.5 Exposure Factors

Plumes of the stacks of the study facility are dispersed in all directions with varying wind speeds and atmospheric stability. The result is that surface receptors, such as soil and vegetation, are not equally exposed to the plume and the deposition of particles and gases.

The atmospheric diffusion model provides a tool for assessing the cumulative variability of meteorological parameters, such as wind speed and wind direction, which affect the diffusion of plumes and deposition. The ATDM was executed using seasonal and annual climatic weather data to determine the relative exposure from stack plumes among the soil and vegatation sampling locations (receptors) in the study area.

The redistribution of trace elements by plumes of facility stacks is completed by the deposition process. Deposition occurs as wet or dry processes. Wet deposition represents the collection of aerosols and gases by falling raindrops to the surface of soil, vegetation leaves, streams, lakes, or other receptors. Dry deposition represents (1) material that gravitationally settles (fallout) on soil, vegetation, etc., (2) material that is impacted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WEST
EAST
(miles)

Figure 26. Pattern of annual rate of deposition (picograms per square meter per second) of zinc resulting from coal-fired sources adjacent to the study area.

onto surfaces (aerosol impaction) such as vegetation and buildings, and (3) gases that are absorbed by vegetation or soils (gaseous absorption) (16).

The relative exposure, or exposure factor, for each of the 64 soil and vegetation sampling plots was determined by dividing the surface air concentration and total deposition with the value at that location having the highest air concentration and highest total deposition, respectively. Exposure factors for seasonal surface air concentration and total annual deposition from the Milton R. Young Power Plant are shown in Figures 27 and 28, respectively.

The maximum surface air concentration, in any direction during the growing season, occurs at a distance of about 8 kilometers, Figure 27. The exposure factors, representing surface air concentration, have small values, near the facility stacks, because the plumes have not become fully mixed through the depth of the boundary layer. As mixing becomes more complete, the exposure factors increase; once mixing produces a uniform concentration downward through the boundary layer, the horizontal spreading of the plume causes the exposure factors to decrease.

The maximum exposure factors, representing total deposition, occur adjacent to the facility, see Figure 28. In fact, the factors decrease to 0.3 within 3 kilometers of the facility stacks providing a very strong gradient of decreasing deposition within 5 kilometers of the stack.

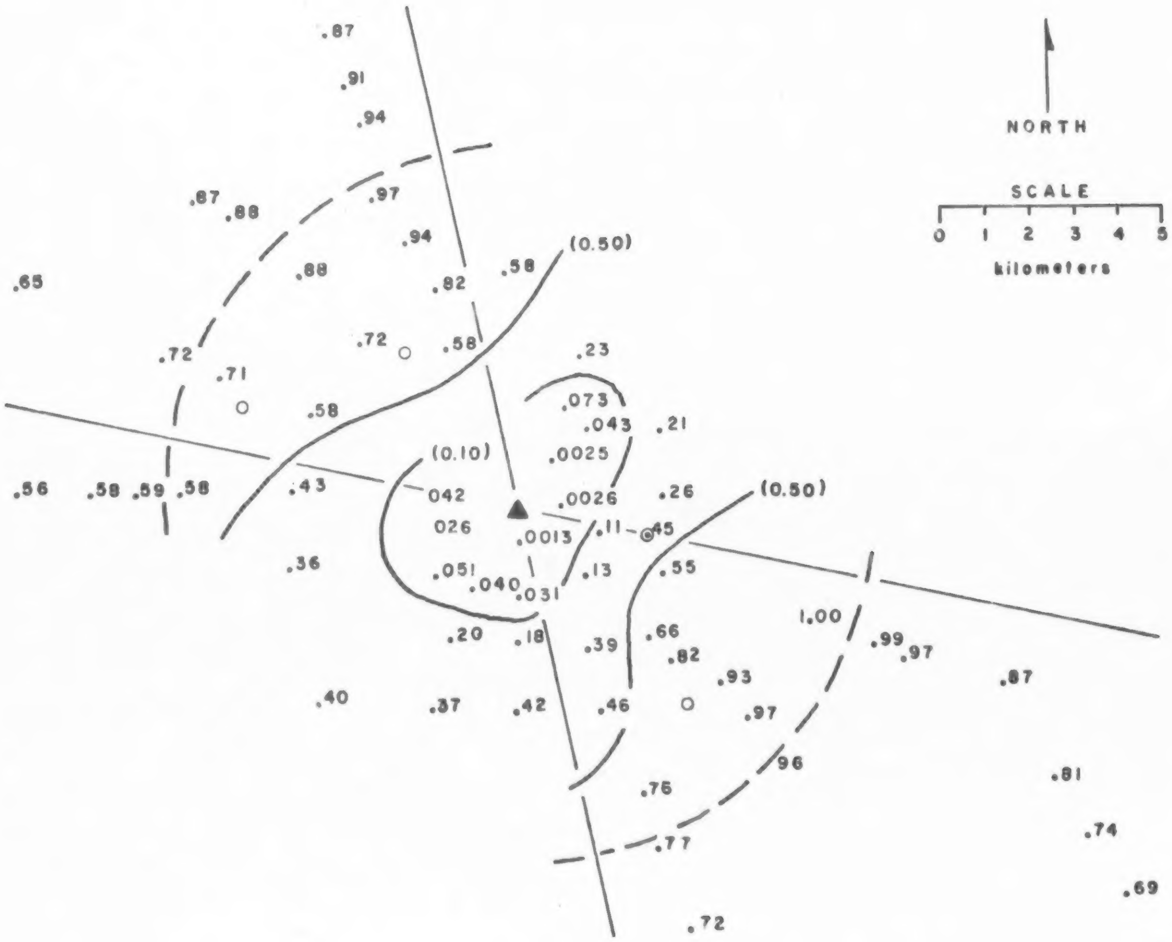
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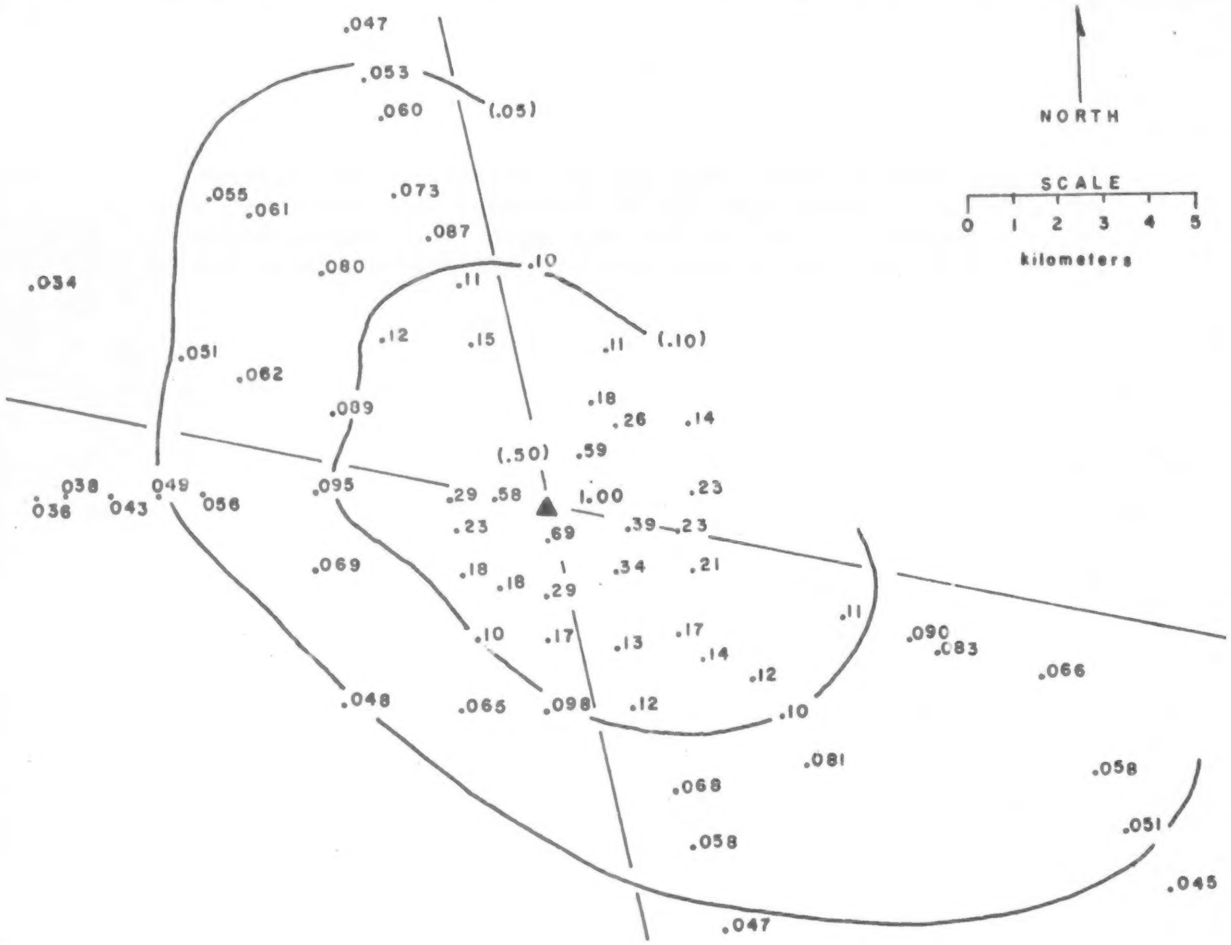
Figure 27. Normalized surface air concentrations for the April-August growing season from ATDM for the 64 field sampling plots. The '▲' marks the location of the MRY Power Plant and the 'o' marks the locations of the four aerosol samplers.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.17
.13
.17
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.12
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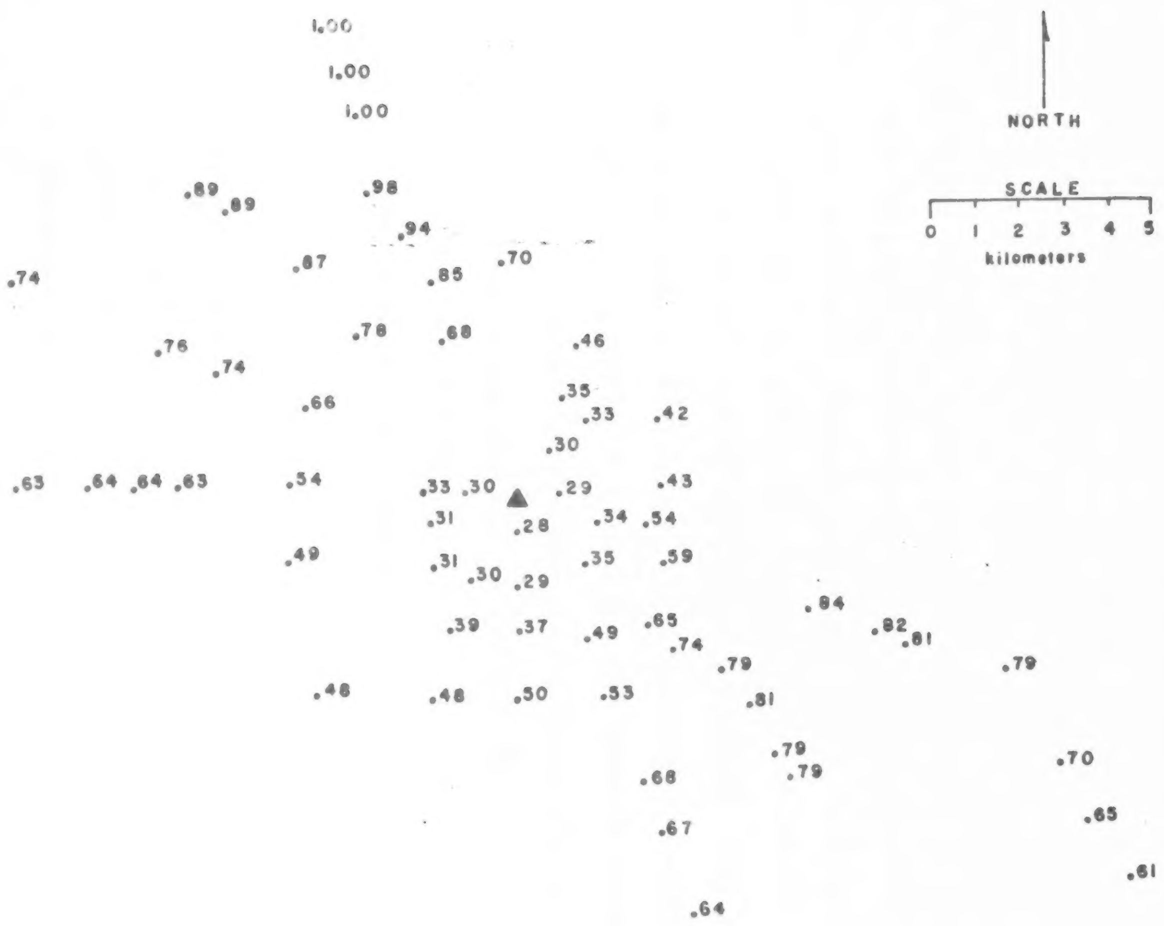
.048
.065
.098
.12
.10
.081
.058
.068
.051
.058
.045
.047

Figure 28. Normalized rates of average annual deposition from ATDM for the locations of the 64 field sampling plots.

The data contained in Figures 27 and 28 apply to any element assuming that air concentration and deposition of the element are independent of particle size. This assumption holds for this analysis, since the particles emitted from the stacks are smaller than 10 micrometers diameter. Larger particles have significant fall speeds, which are greater than 1.0 centimeter per second.

The data also justify the concept that the field receptor sampling scheme should be designed for the specific receptor type and its related interaction with the plume. For example, locations for soil samples should be concentrated near the source. Locations for vegetation samples should be dispersed in the entire area from the source beyond 8 kilometers, since particles deposited on leaf surfaces and/or element molecules can be absorbed into the leaf (17). Several experiments have been conducted to obtain background data on soil and vegetation element concentrations; for example (18, 19). It becomes apparent that such experiments can succeed or fail on the basis of the sampling receptor location pattern.

Exposure factors for the seasonal ground-level air concentration and annual deposition were computed for the 64 plots from zinc emissions for all facilities in and surrounding the study area, Figure 5. The exposure factors for these facilities are shown in Figures 29 and 30.


NORTH
SCALE
0
1
2
3
4
5
kilometers
1.00
1.00
1.00
.89
.89
.98
.94
.74
.87
.85
.70
.76
.74
.78
.68
.46
.66
.35
.33
.42
.30
.63
.64
.64
.63
.54
.33
.30
.29
.43
.31
.28
.34
.54
.49
.31
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.29
.35
.59
.84
.39
.37
.49
.65
.82
.81
.74
.79
.79
.48
.48
.50
.53
.81
.79
.79
.70
.68
.67
.65
.61
.64

Figure 29. Normalized surface air concentration for the April-August growing season for the 64 field sampling plots from all coal-fired facilities in and surrounding the study area.

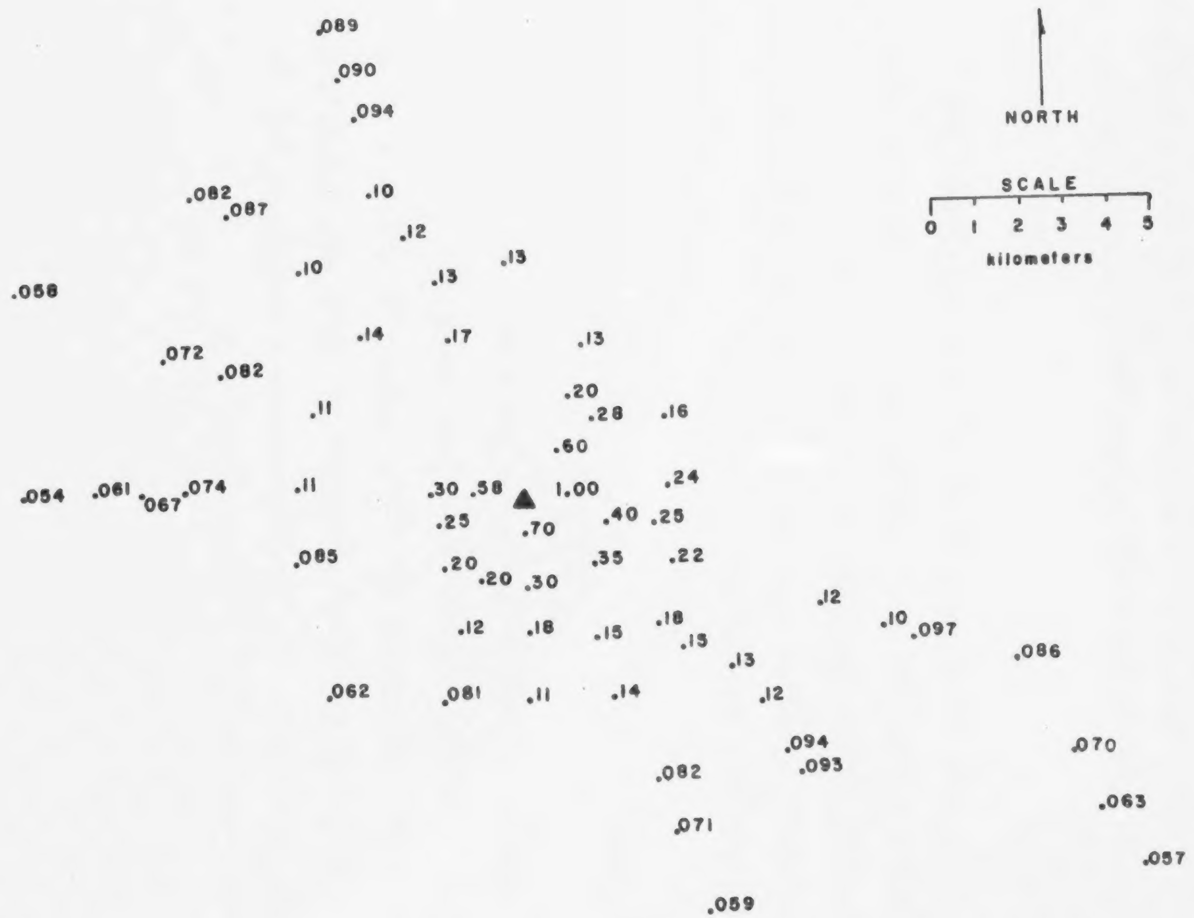
.089
.090
.094
NORTH
.082
.087
.10
SCALE
0 1 2 3 4 5
kilometers
.12
.10
.13
.13
.058
.14
.17
.13
.072
.082
.20
.11
.28
.16
.60
.054
.061
.067
.074
.11
.30
.58
1.00
.24
.25
.70
.40
.25
.085
.35
.22
.20
.20
.30
.12
.12
.18
.15
.18
.15
.10
.097
.086
.13
.062
.081
.11
.14
.12
.094
.093
.070
.082
.063
.071
.057
.059

Figure 30. Normalized rates of average annual deposition from all coal-fired facilities in and surrounding the study area.

The average seasonal ground-level air concentration over sampling plots is maximum in the northwest portion of the study area, Figure 29. Ground-level air concentrations of zinc near the Milton R. Young Power Plant are due to plume contributions from the facilities surrounding the study area, compare Figure 25 to Figure 23.

The average annual rate of deposition at the 64 plots does not change significantly when the surrounding facilities are included in the deposition exposure factors, Figure 30. This result occurs because rates of deposition are small for the facilities at distances beyond five kilometers.

4.4 Aerosol Data

A link in the process of investigating effects of element redistribution is demonstrating that sampled environmental receptors were being exposed to the stack plumes of the coal-fired facility. This evidence removes uncertainties that any anamolies in trace element concentrations in environmental receptors may have been a Type-1 statistical sampling error.

Suspended dust particles are mixed into the atmosphere from the crustal surface of Earth. The forces of wind cause large grains to move on the soil surface. Impaction among the large, moving grains causes suspension of fractured or smaller soil grains. Atmospheric turbulence carries the dust particles upward from the surface once the particles are suspended.

The suspended dust particles contain concentrations of elements, but often in proportions much different than contained in the bulk soil of crustal surface (20). These particles can be directly absorbed by plants through leaf surfaces (16) of vegetation or ingested by breathing of air. Particles less than three micrometers pass through nasal passages of humans into lung cavities (8).

4.4.1 Selection of Samples for Analysis

A total of 232 filters (116 samples), obtained from the four stacked filter units, were selected for elemental analysis. This group comprised all possible pairs (A1-A3, A2-A4) of samples upstream/downstream from the stacks of the study facility. In addition, eight sampling days were chosen when (1) the wind did not blow in a direction from the stacks toward any one of the four sampling sites, and (2) all four samplers were operational.

Subsequent to elemental analysis of the aerosol on the filters, information became available on the characteristics of the 0.4 micrometer (μm) and 12-μm Nucleopore filters, such as levels of mass-loading causing clogging and aerodynamic cutoff diameters as a function of face velocity of the air passing through the filters. Additional information on criteria by which filters were rejected from statistical analyses is presented in Appendix A.

4.4.2 Limitation of Data Set

The volume flow rates of the samplers were affected by analytical error during calibration and measurement, by particle loading on the filters, and by the mechanical sensitivity of the flow by-pass valve on the instrument. These factors can introduce uncertainties into statistical analyses. Therefore, computations below are based on a mass per unit mass of collected dust rather than mass per unit volume of sample air. However, volume flow rate errors will affect concentrations of elements of a given sample uniformly and, thus, not contribute to errors of relative source strength.

From Section 4.2, the mean mass particle diameter of Unit-2 stack effluent was 1.8 micrometers. The effective cutoff diameter of the 12-µm Nucleopore filter was approximately 2.2 micrometers particle diameter, depending on air face velocity which varied from sample to sample (Appendix A). Thus, the analyses presented below does not distinguish between fine or coarse aerosol, diameters less than or greater than 2.2 micrometers, respectively.

4.4.3 Element Concentrations in Aerosols

The concentrations of trace elements in aerosol are characteristic of the sources from which portions of the aerosol originate. The primary sources of aerosol in the study area are: wind blown soil and vegetation particles from prairie and cultivated fields; soil particles from the mine spoil piles, mining activities and mine reclamation; wind blown coal particles from the coal stock pile adjacent to the study facility; and combustion products from vehicles and other equipment. Since the area and the immediate surrounding region are rural, combustion waste products of engines are expected to be a minor fraction of the total aerosol.

The aerosol samples were stratified by wind direction on the supposition that all source contributions to elemental concentrations are equal from all wind directions except the emission plume from stacks of the study facility. However, the large coal pile at the central location, may also contribute to the aerosol concentrations under downstream wind conditions.

The mean concentrations and standard deviations of concentrations of elements for each wind stratification are shown in Tables 13, 14, 15, and 16. The concentrations of the elements vary more than a factor of 400 from about 40 micrograms (μg) per gram (g) for arsenic to about 185,000 μg/g for silicon. Concentrations of elements from sample to sample vary as indicated by the relative magnitudes of standard deviations.

The numbers of samples for each of the wind stratifications are not adequate to statisically evaluate whether differences exist between sampling sites and wind directions. However, it is unlikely that statistical differences could be detected even if a large number of samples had been collected due to weather effects on quantities of aerosol in air (21).

TABLE 13

CONCENTRATIONS OF ELEMENTS IN AEROSOL FOR SITE A1 (μg/g)

	Crosswind	Upstream	Downstream
Number of Samples	5	6	4
Element	mean/std-dev[1]	mean/std-dev	mean/std-dev
Aluminum (Al)	31,220/5,175	34,130/11,510	35,760/1,621
Arsenic (As)	24/30	27/11	45/43
Barium (Ba)	1,160/548	1,150/585	710/475
Bromine (Br)			
Calcium (Ca)	29,450/7,877	26,510/9,337	43,420/8,491
Cadmium (Cd)	176/187	158/83	108/35
Chlorine (Cl)	1,400/441	2,340/1,070	2,270/1,400
Chromium (Cr)	43/21	43/40	46/11
Copper (Cu)	47/29	43/31	49/22
Iron (Fe)	21,580/5,068	21,000/7,806	29,300/5,804
Potassium (K)	10,600/1,550	11,110/2,395	11,050/724
Magnesium (Mg)	9,170/1,080	9,077/2,872	13,160/964
Manganese (Mn)	581/84	598/216	914/236
Sodium (Na)	4,430/1,470	5,860/1,660	4,960/1,130
Nickel (Ni)	47/12	124/178	94/57
Lead (Pb)	1,387/480	1,247/560	2,333/805
Sulfur (S)	26,400/14,300	31,400/17,200	24,800/12,600
Selenium (Se)	155/91	246/134	213/82
Silicon (Si)	169,300/41,030	180,800/62,200	252,900/74,620
Titanium (Ti)	1,530/438	1,990/982	2,120/164
Vanadium (V)	58/12	122/162	86/27
Zinc (Zn)	258/204	214/92	240/53

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[1] Mean is arithmetic mean, std-dev is standard deviation.

TABLE 14

CONCENTRATIONS OF ELEMENTS IN AEROSOL FOR SITE A2 (μg/g)

	Crosswind	Upstream	Downstream
Number of Samples	6	7	8
Element	mean/std-dev	mean/std-dev	mean/std-dev
Aluminum	38,310/14,310	35,280/3,757	37,650/15,880
Arsenic	30/28	44/31	57/63
Barium	1,460/429	1,500/1,130	1,840/776
Bromine			
Calcium	33,870/11,720	34,630/4,447	37,490/9,200
Cadmium	190/68	160/34	379/379
Chlorine	1,530/814	1,870/1,250	2,080/1,490
Chromium	48/37	52/26	54/36
Copper	55/20	58/41	55/30
Iron	24,640/6,967	22,850/5,194	28,310/7,140
Potassium	12,450/3,290	11,680/1,640	11,650/1,602
Magnesium	8,890/3,610	10,040/1,410	9,500/1,610
Manganese	601/210	669/126	682/128
Sodium	4,720/1,190	5,440/2,400	3,930/896
Nickel	51/21	54/20	60/37
Lead	1,340/245	1,530/948	1,160/301
Sulfur	27,400/7,800	32,000/14,000	27,300/16,300
Selenium	186/60	192/108	270/89
Silicon	190,400/61,300	185,600/37,490	199,400/49,980
Titanium	2,070/504	2,010/382	2,130/472
Vanadium	75/21	70/15	75/52
Zinc	252/120	271/187	212/86

TABLE 15

CONCENTRATIONS OF ELEMENTS IN AEROSOL FOR SITE A3 (µg/g)

	Crosswind	Upstream	Downstream
Number of Samples	6	8	4
Element	mean/std-dev	mean/std-dev	mean/std-dev
Aluminum	28,750/9,432	37,680/9,603	37,790/17,270
Arsenic	37/45	50/37	40/31
Barium	1,610/655	1,780/1,050	1,270/838
Bromine			
Calcium	34,000/12,460	41,480/5,835	29,000/3,350
Cadmium	253/183	195/145	223/188
Chlorine	2,370/1,160	2,060/1,320	2,240/692
Chromium	71/67	65/47	30/8
Copper	40/23	69/25	37/35
Iron	23,360/7,824	25,100/4,266	21,000/5,040
Potassium	11,500/1,780	11,090/2,270	11,100/2,360
Magnesium	9,760/3,140	8,470/3,210	10,180/2,930
Manganese	620/160	620/155	659/233
Sodium	5,400/2,640	5,970/5,180	6,160/1,530
Nickel	39/8	73/33	42/21
Lead	1,218/367	1,645/889	1,000/255
Sulfur	28,400/19,500	33,000/18,200	32,600/13,300
Selenium	197/100	215/139	207/74
Silicon	172,700/53,880	175,500/44,140	169,900/40,500
Titanium	1,900/609	2,280/699	1,770/440
Vanadium	59/15	80/30	68/30
Zinc	281/212	243/156	256/96

TABLE 16

CONCENTRATIONS OF ELEMENTS IN AEROSOL FOR SITE A4 (μg/g)

	Crosswind	Upstream	Downstream
Number of Samples	3	7	3
Element	mean/std-dev	mean/std-dev	mean/std-dev
Aluminum	25,380/3,734	33,340/8,559	32,620/5,257
Arsenic	31/19	31/13	33/7
Barium	1,180/348	1,200/619	699/170
Bromine			
Calcium	25,080/4,227	32,400/14,750	28,900/5,600
Cadmium	257/47	202/90	168/4
Chlorine	1,870/168	1,970/757	1,490/241
Chromium	46/24	48/20	106/147
Copper	57/22	47/24	34/20
Iron	21,360/6,585	27,720/13,190	23,060/3,701
Potassium	11,300/2,250	12,300/2,280	11,100/1,920
Magnesium	7,830/933	9,650/3,500	9,740/1,610
Manganese	491/79	667/256	630/57
Sodium	4,420/1,480	4,360/1,280	4,140/764
Nickel	169/200	43/22	45/32
Lead	1,650/827	1,310/463	1,350/304
Sulfur	34,600/16,100	29,800/16,700	27,900/2,420
Selenium	237/138	250/175	234/52
Silicon	156,900/44,700	192,800/63,740	177,100/18,740
Titanium	1,530/431	1,860/577	1,790/251
Vanadium	49/12	63/12	65/11
Zinc	403/298	245/86	193/44

The mean concentrations and standard deviations for all samples are shown in Table 17. Since it is not known whether the weather conditions during which the samples were obtained are representative of the sampling season, it cannot be concluded that the concentrations in Table 17 are representative of the daily exposure by living organisms to the aerosol. Rather, the concentrations are indicative of levels of element concentrations in aerosols.

4.4.4 Element Enrichment in Aerosol

The concentrations of elements can be related to a natural geochemical origin with a relative enrichment factor (EF). This procedure reduces the variance caused by weather effects on particulate loading and sampling error. The factor, computed for each element, is defined by:

$$EF = \frac{(C_x/C_{Al})_a}{(C_x/C_{Al})_{soil}}$$

where C_X and C_{Al} are concentrations of element X and Al, respectively, in material a (aerosol) or soil. Aluminum is commonly chosen as the normalizing or reference element because of its low sample-to-sample and temporal variation.

The denominator represents the crustal pattern of elements. Therefore, a value for EF greater than unity has been interpreted to indicate an enrichment of the element in the aerosol by

TABLE 17

CONCENTRATIONS OF ELEMENTS IN AEROSOL
(All Sampling Sites and Wind Directions Included)

Number of Samples	67
Element	Concentration (µg/g) mean/std. dev.
Aluminum	34,540/10,850
Arsenic	39/34
Barium	1,380/764
Bromine	
Calcium	33,810/10,000
Cadmium	212/175
Chlorine	1,980/1,030
Chromium	54/44
Copper	51/28
Iron	24,440/7,228
Potassium	11,480/2,000
Magnesium	9,550/2,610
Manganese	645/181
Sodium	5,010/2,320
Nickel	66/73
Lead	1,410/625
Sulfur	29,700/14,300
Selenium	218/109
Silicon	185,900/51,760
Titanium	1,960/561
Vanadium	74/53
Zinc	251/141

anthropogenic sources: for example, lead, bromine, and chlorine from leaded gasoline; zinc and cadmium from refuse incineration; chlorine from ocean sources; vanadium from residual oil; arsenic, lead, and selenium from coal (10, 21).

Within the study area, 20 surface soil samples were taken to a depth of 1.3 centimeters, see Section 3.10. The mean concentrations of elements from these samples were used to represent the crustal pattern of the elements. Concentrations for arsenic, barium, bromine, chlorine, silicon, and vanadium were not chemically analyzed in the soil samples; therefore, crustal patterns were obtained from other research (22). The relative concentrations of elements in soil, which were used to calculate EF for the aerosol, are given in Table 40.

Element enrichment factors for upstream, downstream, and crosswind wind directions are shown for each sampling site in Tables 18, 19, 20, and 21. Again, the number of samples is insufficient for statistical analyses of differences among sites and wind directions.

Examination of the tables suggests that enrichment of certain elements is occurring. However, the differences in enrichment factors for these elements are not consistant from sampling site to sampling site. For example, both sites A2 and A3 are located south-easterly of the study facility: the EF for arsenic at site A2 is larger under downstream relative to upstream wind conditions while it is much lower at site A3.

TABLE 18

AEROSOL ELEMENT ENRICHMENT FACTORS
FOR SITE A1

Element	Crosswind mean/std-dev[1]	Upstream mean/std-dev	Downstream mean/std-dev
Aluminum	1.0/0.0	1.0/0.0	1.0/0.0
Arsenic	12.4/16.8	14.1/10.0	23.7/22.1
Barium	5.5/3.4	6.1/6.0	2.3/1.5
Bromine			
Calcium	5.3/3.4	4.3/0.62	8.3/5.0
Cadmium	653/783	621/636	409/283
Chlorine	11.3/4.9	21.4/19.7	28.9/40.3
Chromium	1.4/0.51	1.6/1.7	1.9/1.7
Copper	4.2/3.2	4.0/3.5	3.5/0.40
Iron	1.6/0.26	1.4/0.16	2.3/1.3
Potassium	1.1/0.036	1.1/0.25	1.3/0.93
Magnesium	2.4/0.34	2.2/0.47	4.1/3.6
Manganese	1.9/0.26	1.8/0.22	3.2/1.8
Sodium	0.76/0.34	0.98/0.48	1.0/0.92
Nickel	3.2/0.60	8.3/10.8	10.4/14.3
Lead	99/48	98/90	160/70
Sulfur	145/96	186/175	183/217
Selenium	488/352	864/860	840/855
Silicon	1.2/0.13	1.1/0.17	1.8/0.88
Titanium	0.84/0.12	0.98/0.34	1.3/0.94
Vanadium	1.3/0.19	2.1/2.0	1.9/0.62
Zinc	5.6/5.3	4.5/2.2	6.5/6.9

---

[1] Mean is arithmetic mean, std-dev is standard deviation.

TABLE 19

AEROSOL ELEMENT ENRICHMENT FACTORS FOR SITE A2

Element	Crosswind mean/std-dev	Upstream mean/std-dev	Downstream mean/std-dev
Aluminum	1.0/0.0	1.0/0.0	1.0/0.0
Arsenic	13.5/14.0	17.9/13.4	23/26
Barium	6.1/2.8	6.4/5.5	7.7/4.0
Bromine			
Calcium	5.4/2.1	5.4/0.89	5.9/1.8
Cadmium	629/4.7	484/133	1180/1170
Chlorine	11.1/7.2	13.5/10.5	15.3/11.2
Chromium	1.4/0.80	1.6/0.84	1.6/1.2
Copper	4.3/2.6	4.4/3.5	4.6/3.6
Iron	1.6/0.64	1.50/0.27	1.8/0.59
Potassium	1.1/0.39	1.0/0.99	1.0/0.22
Magnesium	2.0/0.79	2.3/0.30	2.2/0.45
Manganese	1.7/0.59	2.0/0.38	2.1/0.64
Sodium	0.73/0.35	0.82/0.44	0.58/0.20
Nickel	3.4/2.1	3.4/1.6	3.8/2.8
Lead	81/28	96/69	75/33
Sulfur	132/80	149/79	139/106
Selenium	507/287	534/337	777/385
Silicon	1.2/0.39	1.1/0.19	1.2/0.28
Titanium	1.0/0.37	0.99/0.21	1.0/0.21
Vanadium	1.4/0.21	1.4/0.39	1.3/0.32
Zinc	5.1/4.2	5.1/4.0	4.1/2.1

TABLE 20

AEROSOL ELEMENT ENRICHMENT FACTORS FOR SITE A3

Element	Crosswind mean/std-dev	Upstream mean/std-dev	Downstream mean/std-dev
Aluminum	1.0/0.0	1.0/0.0	1.0/0.0
Arsenic	20/30	22/18	13.7/4.1
Barium	8.4/4.5	8.1/7.5	4.5/2.0
Bromine			
Calcium	6.8/2.7	6.5/2.4	4.7/1.5
Cadmium	1050/978	680/826	582/257
Chlorine	23.1/15.5	16.2/14.8	15.8/6.9
Chromium	3.5/4.6	2.0/1.6	1.0/0.59
Copper	4.2/5.3	5.4/3.6	3.1/2.8
Iron	2.0/0.91	1.6/0.34	1.4/0.26
Potassium	1.4/0.47	0.94/0.19	0.98/0.23
Magnesium	2.8/0.88	1.9/0.69	2.3/0.49
Manganese	2.4/1.0	1.8/0.48	1.9/0.30
Sodium	1.2/0.90	0.87/0.86	0.91/0.35
Nickel	3.3/1.6	4.7/3.0	2.3/0.85
Lead	99/44	107/89	65/28
Sulfur	186/176	156/115	162/102
Selenium	749/576	562/409	611/377
Silicon	1.4/0.74	1.0/0.20	1.0/0.19
Titanium	1.2/0.54	1.1/0.33	0.86/0.15
Vanadium	1.5/0.24	1.5/0.45	1.3/0.042
Zinc	7.5/7.3	4.3/3.1	4.9/2.3

TABLE 21

AEROSOL ELEMENT ENRICHMENT FACTORS FOR SITE A4

Element	Crosswind mean/std-dev	Upstream mean/std-dev	Downstream mean/std-dev
Aluminum	1.0/0.0	1.0/0.0	1.0/0.0
Arsenic	16.5/7.6	13.8/7.0	15.0/5.5
Barium	6.8/2.8	5.6/4.0	3.0/0.42
Bromine			
Calcium	5.4/0.41	5.2/1.7	4.9/1.2
Cadmium	1080/271	690/409	550/93
Chlorine	18.2/3.2	16.2/9.2	11.3/2.5
Chromium	1.87/0.69	1.5/0.52	3.9/5.7
Copper	6.1/2.9	3.7/1.7	2.8/1.9
Iron	1.9/0.40	1.9/0.58	1.7/0.40
Potassium	1.4/0.18	1.2/0.22	1.1/0.35
Magnesium	2.5/0.23	2.3/0.38	2.4/0.19
Manganese	2.0/0.046	2.0/0.33	2.0/0.29
Sodium	0.92/0.42	0.72/0.33	0.67/0.22
Nickel	14.9/18.0	2.7/1.0	3.2/2.7
Lead	145/88	93/58	87/13.2
Sulfur	228/127	167/136	138/29
Selenium	924/587	855/848	674/158
Silicon	1.3/0.31	1.2/0.27	1.2/0.30
Titanium	1.1/0.33	0.97/0.23	0.97/0.25
Vanadium	1.3/0.21	1.4/0.18	1.4/0.22
Zinc	10.6/8.9	5.1/2.8	3.9/1.4

4.4.5 Fine Versus Coarse Filter Analysis

As previously indicated, sample-to-sample variability of face velocity on the filters was evident by wide fluctuations in the air volume flow measurements taken at the end of each 24-hour sample. This sampling problem caused sample-to-sample and within sample variations of the particle effective cutoff diameter by the 12-micrometer (μm) filter. The magnitudes of these variations are unknown; primarily due to measurements of sampler air volume flow only at the beginning and end of each 24-hour sample.

The analysis below is provided in spite of this limitation, since it offers some insight into the coal, soil, and vegetation phases of this project. It also provides an indication of element differences between respirable and nonrespirable fractions of suspended particulates.

The average element enrichment factors for particulate fractions collected on the 0.4-μm (fine) and 12-μm (coarse) filters are shown in Table 22. Substantial differences occur between the element enrichment factors of the two filters for arsenic, barium, cadmium, chromium, copper, nickel, lead, sulfur, selenium, and zinc. For each of these elements, the average of fine filter enrichment factors exceeded the average of coarse filter enrichment factors. A statistical analysis to determine levels of significance of the differences between enrichment factors

TABLE 22

AEROSOL ELEMENT ENRICHMENT FACTORS FOR FINE AND COARSE FILTERS -- ALL SITES

	Fine Filter/Coarse Filter		
Element	Crosswind	Upwind	Downwind
Arsenic	46.4/0.3	51.4/4.3	59.3/8.9
Barium	11.3/4.7	14.7/4.0	10.2/3.9
Calcium	5.8/7.2	6.7/5.1	6.3/7.6
Cadmium	1,340/587	1,050/478	1,368/783
Chlorine	22.9/15.5	24.2/14.5	20.8/28.5
Chromium	2.9/3.4	4.1/0.8	3.8/1.6
Copper	5.1/5.2	8.4/3.0	7.3/3.4
Iron	1.9/2.2	2.0/1.5	2.1/2.2
Potassium	1.6/1.3	1.4/0.9	1.3/1.2
Magnesium	2.3/2.9	2.2/2.1	2.4/3.5
Manganese	2.1/2.4	2.0/1.9	2.3/2.9
Sodium	1.4/0.8	1.1/0.8	1.0/0.9
Nickel	3.0/7.2	8.4/3.1	7.6/4.6
Lead	254/39.2	285/33.7	328/34.1
Sulfur	465/36.6	518/38.1	457/44.7
Selenium	1,015/621	1,366/475	1,302/653
Silicon	1.0/1.8	1.0/1.2	1.0/1.8
Titanium	1.0/1.3	1.1/1.0	1.1/1.3
Vanadium	1.6/1.4	2.0/1.4	1.6/1.5
Zinc	15.8/3.2	11.4/2.2	10.3/2.9

for the fine and coarse filters was not conducted due to the limitation of the data described above.

A linear regression analysis of the form $FEF_x = a_0 + b_1 CEF_x$ was performed where FEF_x was fine filter enrichment factor for element x, CEF_x was coarse filter enrichment factor, and a_0 and b_1, were the intercept and slope of the regression line. The results of the analysis are shown in Table 23. The limitation described above may have contributed to the lack of significant relationships between FEF_x and CEF_x.

Differences between upstream and downstream linear regression relationships could be expected if samplers sampled the stack plume and if outside sources didn't interfere (contaminate the experiment) with upstream air.

4.5 Snow Data

Enrichment, or scavenging, of elements in snow particles may provide a source of elements to the underlying soil and to watershed runoff from snowmelt. Enrichment of pollutants has been reported in the first spring snowmelt of watershed runoff water (23). If snowmelt contains enriched quantities of elements, it can redistribute the elements to impounded water, or other water sinks.

The scavenging of elements by snow particles may possibly occur (1) by sublimation of molecules in the form of the gaeous phase

TABLE 23

LINEAR REGRESSION ANALYSIS OF FINE VERSUS COARSE FILTER ELEMENT ENRICHMENT FACTORS

		$a_0/b_1/P>\lvert T\rvert$ [1]	
Element	Crosswind	Upstream	Downstream
Arsenic	48.0/-5.15/0.60	46.8/1.07/0.42	58.3/0.11/0.89
Barium	5.9/1.2/<0.01	2.1/3.1/<0.01	8.5/0.44/0.33
Calcium	6.0/-0.03/0.49	1.1/1.11/<0.01	6.1/0.02/0.61
Cadmium	431.5/1.55/<0.01	-157.9/2.52/<0.01	772.4/0.76/0.13
Chlorine	21.2/0.12/0.72	3.6/1.42/<0.01	20.0/0.03/0.54
Chromium	3.0/-0.01/0.83	4.0/0.13/0.89	3.3/0.34/0.21
Copper	5.7/-0.10/0.43	4.1/1.45/0.08	7.7/-0.13/0.78
Iron	1.9/-0.03/0.22	1.5/0.32/0.26	2.1/0.01/0.93
Potassium	1.7/-0.12/0.15	1.7/-0.25/0.33	1.3/0.01/0.81
Magnesium	2.4/-0.03/0.56	2.6/-0.16/0.24	1.9/0.14/<0.01
Maganese	2.1/0.02/0.63	0.8/0.68/0.07	2.3/-0.001/0.97
Sodium	1.2/0.21/0.49	-0.1/1.6/ 0.01	1.0/0.03/0.70
Nickel	3.2/-0.02/0.65	11.4/-0.97/0.60	5.1/0.54/<0.01
Lead	213.9/1.02/0.50	78.6/6.1/<0.01	315.5/0.37/0.88
Sulfur	215.4/6.81/0.05	175.5/9.00/<0.01	431.4/0.58/0.54
Selenium	961.9/0.08/0.81	-214.3/3.32/<0.01	1,256/0.07/0.79
Silicon	1.0/-0.02/0.25	1.1/-0.07/0.57	1.0/-0.01/0.80
Titanium	1.1/-0.03/0.50	1.0/0.11/0.61	1.1/0.03/0.50
Vanadium	1.7/-0.09/0.79	1.4/0.41/0.79	1.1/0.31/0.05
Zinc	1.2/4.52/0.01	0.9/4.86/<0.01	8.5/0.61/0.09

---

[1] a_0 is intercept, b_1 is slope or coefficient of coarse filter element enrichment factor, $P>|T|$ is Probability (P) that b_1 is equal to zero.

of the element to the snow particle, (2) by collection of stack aerosol by the falling snow particles, and/or (3) by nucleation of water vapor on the stack aerosol. Samples of the snowfall were collected to identify whether scavenging of elements by snowfall was a potential mechanism for deposition of the elements.

4.5.1 Selected Elements

The anions selected for analysis were fluoride (F^-), chloride (Cl^-), sulfate ($SO_4^=$), and nitrate (NO_3^-). Cations selected for chemical analysis were mercury (Hg^{++}), arsenic (As^{+++}), and selenium (Se^{++++}). F^-, Cl^-, Hg^{++}, As^{+++}, and Se^{++++} are known to occur primarily in the gaseous phase within the stack gas waste stream (24).

4.5.2 Concentration Patterns

The concentrations of the anions and cations have been plotted to identify a possible pattern of deposition. The skattergrams are presented in Figures 31 and 32.

The concentrations of selenium in the snow samples were less than detectable levels of the analytical technique, with one exception which was the nearest downstream site. The concentrations for fluoride, chloride, and sulfate are correlated (Table 24), but they do not indicate any form of a deposition pattern. Nitrate concentrations are better correlated to sulfate than the other anions.

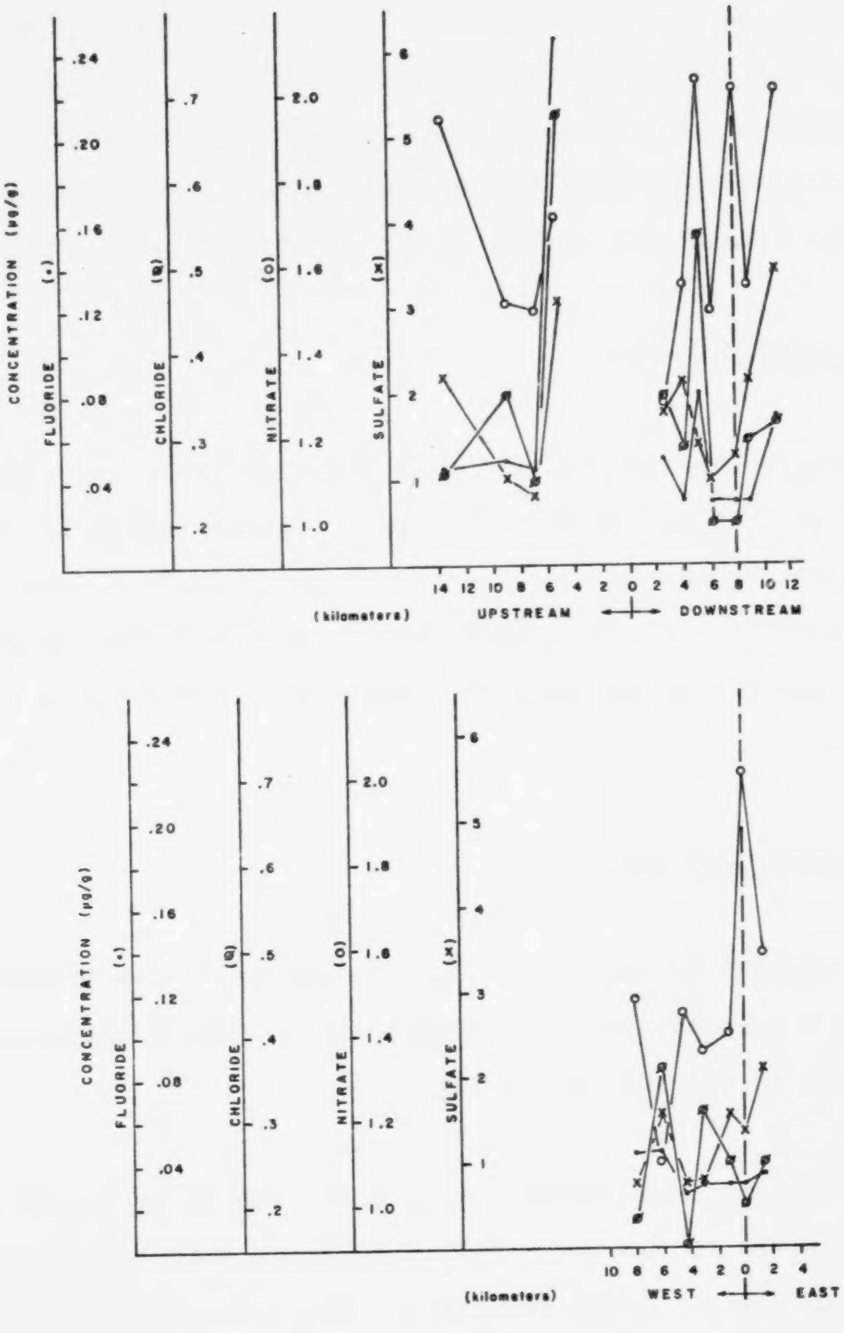

Figure 31. Scattergrams of anion concentrations in snow samples.

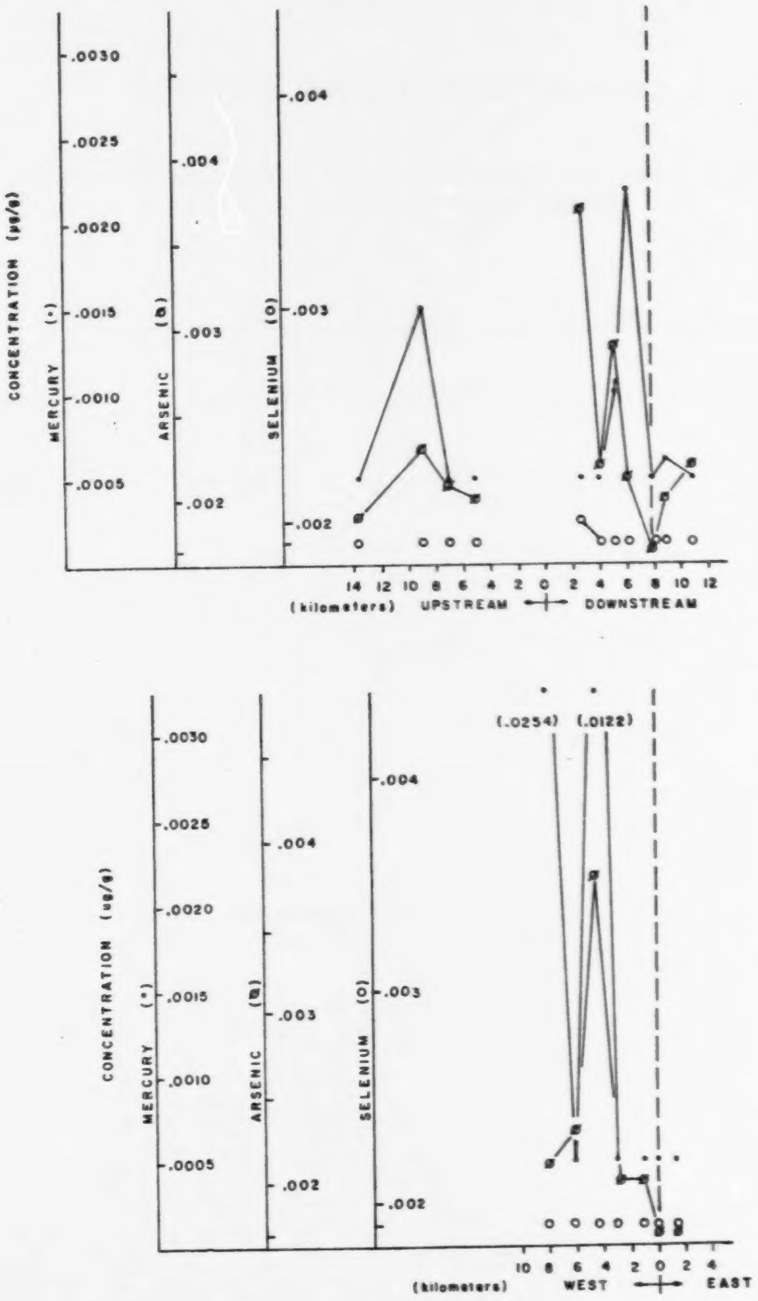

Figure 32. Scattergrams of cation concentrations in snow samples.

TABLE 24

CORRELATION MATRIX FOR SNOW DATA

(Correlation Coefficient/Probability of $\geq |R|$
Under Hypothesis of $R = 0$)

	As	Hg	SO_4	NO_3	Cl
Fluorine, F	.04/.86	.11/.65	.52/.02	.29/.23	.76/.0001
Chloride, Cl	.17/.47	-.26/.29	.36/.13	.22/.36	
Nitrate, NO_3	-.14/.56	-.11/.66	.39/.10		
Sulfate, SO_4	-.17/.49	-.42/.08			
Mercury, Hg	.24/.32				
Arsenic, As					

The skattergram for mercury and arsenic suggest a plume effect downstream of the study facility with the effect more pronounced for arsenic. Further, the crosswind transect suggests that the greatest deposition likely occurred on a downwind transect which was more southerly, and therefore, that the wind direction during the snowfall was more northerly, rather than from the northwest.

4.6 Rain Data

Four samples of rainfall were successfully collected. High wind speeds caused a problem with the collection buckets of the sampler; the problem was corrected later in the season.

The concentrations of selected trace elements in the rain samples are shown in Table 25. The data are insufficient for interpreting rainfall washout of stack plumes.

4.7 Aquatic Data

The data base for the aquatic analysis consists of weekly sampling from mid-May through September of 1978, and four weeks in April of 1979, for a total of 22 weeks of sampling.

4.7.1 Limitations of Data Set

The aquatic portion of this study was designed to provide baseline information on the concentration of ten trace elements. Due to considerations of time, manpower, and monetary constraints, a

TABLE 25

TRACE ELEMENTS CONCENTRATIONS IN RAINFALL SAMPLES

Sampling Date	6/76	7/3	7/10	7/24
Primary Wind Direction	NE	ESE-SE	SE	S-SW
Element	Concentration (µg/l)[1/]			
Arsenic	1	1		1
Copper	2.6	1.4	3.0	2.1
Cadmium	0.21	0.11	0.21	0.12
Chromium	1	0.5	0.5	0.5
Lead	1.8	1.6	3.8	0.9
Mercury				
Molybdenum	3		3	2
Nickel	3	3	8.1	5.6
Selenium	8.1	5.6	2	2
Zinc	14	8.7	19.0	6.1

[1/] A < indicates the concentration was less than the level shown.

number of significant parameters were omitted from analytical consideration. For example, the concentration of major cations (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) and anions (CO_3^{--}, $SO_4^{=}$, Cl^{-}, & HCO_3^{-}) were not determined. Their concentration in water is very useful in describing the chemical density as a fitness factor and an indicator of the edaphic relationship which contributes to productivity within a body of water. Their concentration may also have a direct influence on the toxic and cycling activities of elements.

From the standpoint of mobility of elements, redox-sensitive hydrous oxides of iron and manganese should have been examined. Alternating conditions of reduction and oxidation may result in the release and sorption of elements from hydrous oxide surfaces and may lead to a dynamic cycling of selected elements in aquatic ecoysystems.

All water samples, except those collected for mercury analysis, were filtered through a 0.45-micron Millipore filter.

4.7.2 Sampling System

The surface water sampling locations were designed to approximate element inputs into and outputs from Nelson Lake. For example, site locations 1 and 2 provide measurements of water entering the lake system. Site location 4 represents a measurement of the combined inputs of sites 2 and 9. Site 8 represents the cooling water entering the study facility and site 9 represents conditions of cooling water discharge from the study facility.

Since water was not discharged from the dam of Nelson Lake during the sampling period in 1978, output from the lake system did not occur, other than surface evaporation losses. Sites 10 and 11 represent drainage runoff into Square Butte Creek downstream of the Nelson Lake dam and surface discharge through springs from groundwater aquifers.

4.7.3. Temperature Measurements

The four stream sites, Figure 33, had a mean surface temperature of 20 degrees Centigrade (C) during 1978 and an average of 2.4 C for April, 1979. A low reading of 0.5 C was recorded at all stream sites in April 1979, and a high of 26 C was recorded at sites 2, 10, and 11 in July, 1978.

The lake sites (3-8) had a mean surface temperature of 30.1 C and a corresponding bottom temperature of 27.0 C in 1978. The mean surface temperature for these sites averaged 11.7 C during April 1979.

Site 9, located at the source of the cooling water discharge canal, had a high of 39 C recorded in 1978 and a low of 11 C in April of 1979. The average temperature for 1978 was 35.5 C.

MEAN MONTHLY TEMPERATURE (degree Centigrade)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	2.3	18.5	19.6	22.0	20.7	15.7
2	1.9	19.5	19.5	22.6	21.0	15.0
Canal:						
9	18.8	33.5	35.3	37.4	37.0	33.0
4	17.4	32.5	33.3	36.3	36.5	32.8
Lake:						
3	10.5	28.0	25.4	30.3	28.0	24.3
5	---	30.3	31.6	35.4	35.0	31.3
6	11.9	27.5	28.5	32.2	31.7	28.7
7	9.5	26.5	26.9	30.3	30.0	26.0
8	9.0	25.0	26.1	29.8	29.3	25.0
Downstream:						
10	2.9	19.0	20.3	23.0	21.3	16.0
11	2.8	18.5	20.0	23.2	21.7	16.0

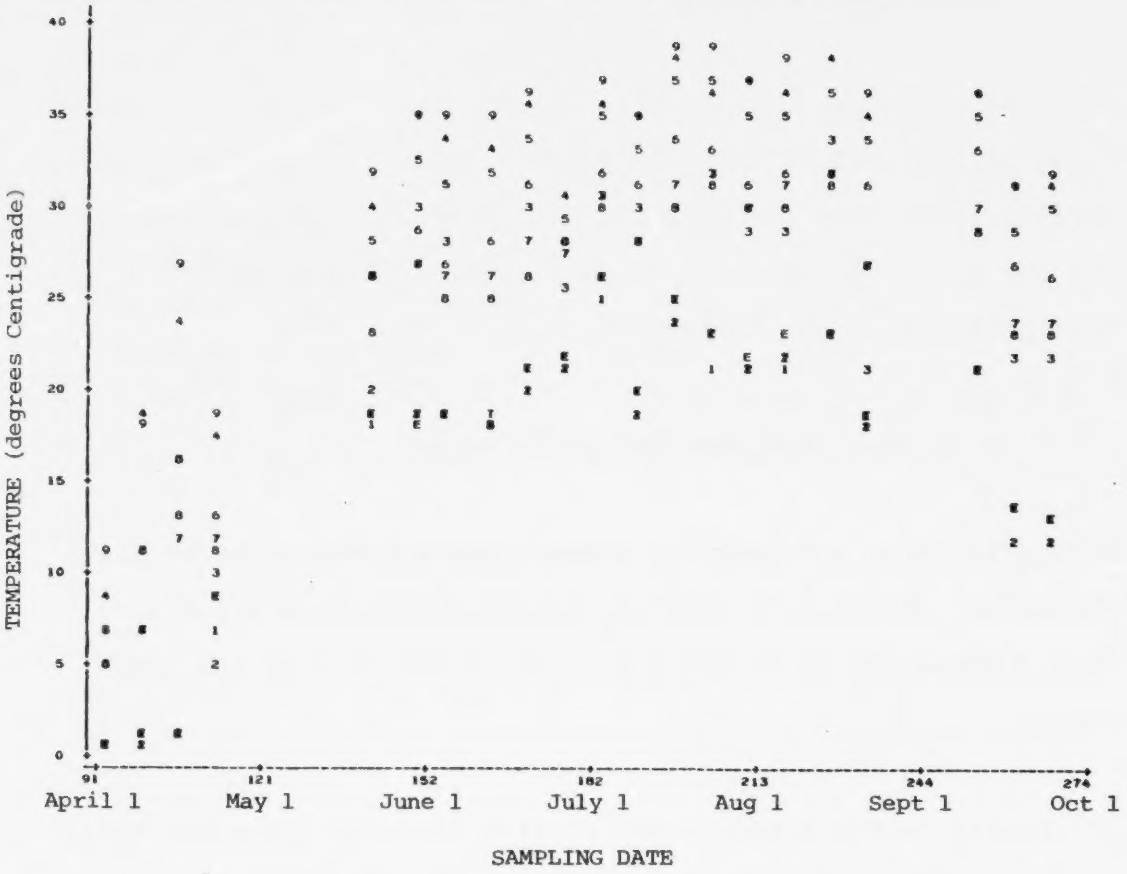

Figure 33. Seasonal and location variations of surface water temperature.

Site 4, located at the mouth of the cooling discharge canal and about 0.8 kilometers from site 9 had a high of 38 C in 1978 and a low of 9 C in 1979. The average for 1978 was 34.5 C.

4.7.4 pH Measurements

The pH parameter averages about 8.0 in the stream sites and about 8.3 in the lake sites with a corresponding drop of about one unit at all sites in April of 1979 (Figure 34).

4.7.5 Dissolved Oxygen

With the exception of site 2 in which stream flow was impeded by a beaver dam, values of dissolved oxygen content became slightly smaller throughout the 1978 sampling period. Seasonal averages for all sites, except site 2, were similar, averaging 6.8 milligrams per liter (Figure 35).

4.7.6 Alkalinity and Specific Conductance

Both alkalinity and specific conductance exhibit fluctuations throughout the 1978-79 sampling period (Figures 36 and 37). This fluctuation is directly related to stream flow and lake level.

Alkalinity in the stream sites in 1978 averaged about 400 milligrams per liter; whereas, the lake sites averaged about 170 milligrams per liter. In April of 1979, an opposite trend from

MEAN MONTHLY pH

Site Number	April	May	June	July	August	Sept
Upstream:						
1	7.41	8.39	7.71	7.94	8.08	8.19
2	7.53	8.07	8.20	7.84	8.00	8.29
Canal:						
9	7.39	8.58	8.12	8.47	8.40	8.35
4	6.68	8.54	8.25	8.76	8.50	8.47
Lake:						
3	7.18	7.93	8.15	8.15	8.27	8.41
5	---	8.11	8.26	8.75	8.55	8.51
6	7.61	8.59	8.37	8.71	8.61	8.58
7	7.90	8.24	8.41	8.67	8.61	8.65
8	8.01	8.24	8.36	8.71	8.62	8.67
Downstream:						
10	7.42	8.22	8.11	8.04	8.10	8.28
11	7.43	8.33	8.06	8.27	8.18	8.31

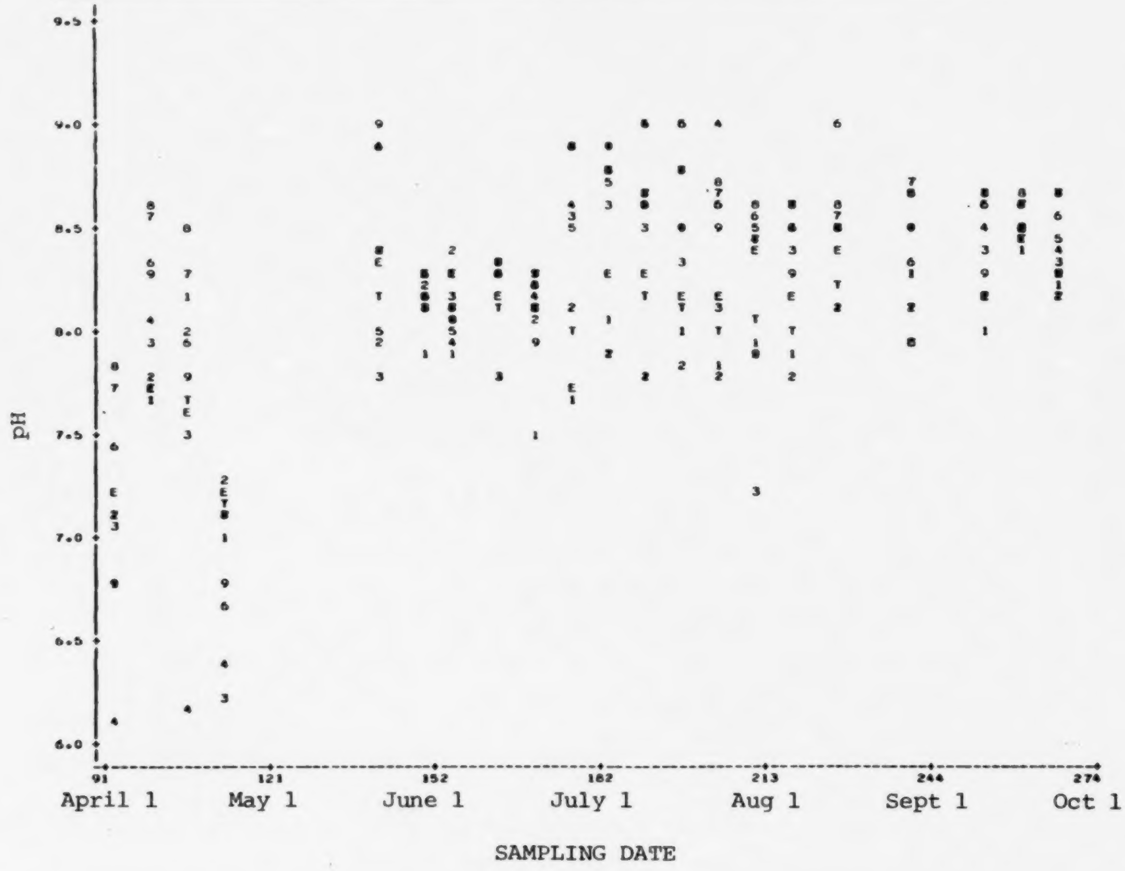

Figure 34. Seasonal and location variations of surface water pH.

MEAN MONTHLY DISSOLVED OXYGEN (milligrams/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	---	6.46	6.47	7.30	7.25	6.43
2	---	8.08	6.57	4.51	3.55	5.07
Canal:						
9	---	---	---	---	---	---
4	---	6.88	6.90	6.98	6.50	6.60
Lake:						
3	---	6.80	6.83	6.76	6.10	6.50
5	---	6.65	6.70	6.78	6.31	6.67
6	---	6.80	6.65	6.65	6.24	6.50
7	---	6.88	6.85	7.19	6.66	6.77
8	---	7.16	7.83	7.71	6.85	6.53
Downstream:						
10	---	6.39	6.87	6.36	6.51	7.03
11	---	6.84	8.28	6.75	6.73	7.77

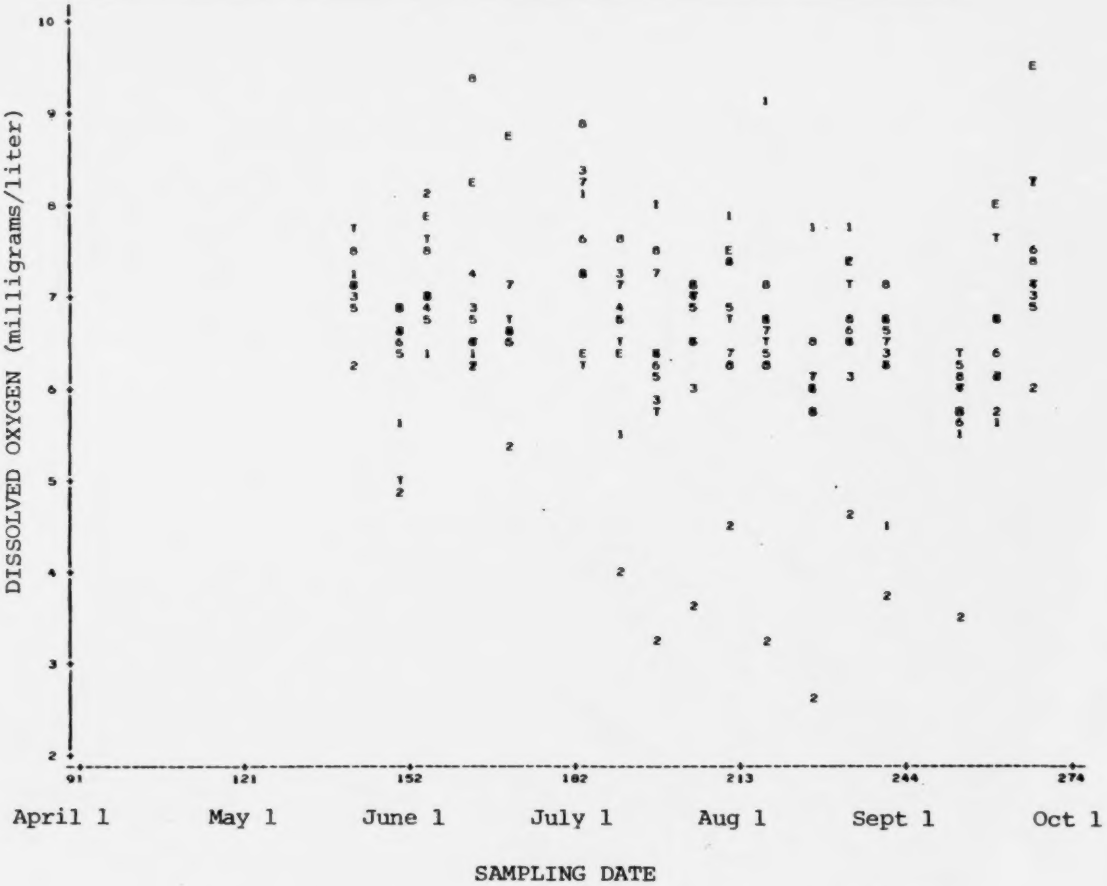

Figure 35. Seasonal and location variations of surface water dissolved oxygen.

MEAN MONTHLY ALKALINITY (milligrams/liter as $CaCO_3$)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	222	---	379	370	398	415
2	224	---	332	290	388	389
Canal:						
9	197	---	153	158	174	189
4	195	---	166	160	173	187
Lake:						
3	217	---	159	164	177	193
5	---	---	156	162	174	190
6	199	---	157	162	173	200
7	198	---	155	158	175	192
8	198	---	153	160	172	191
Downstream:						
10	192	---	420	382	394	340
11	193	---	451	416	417	352

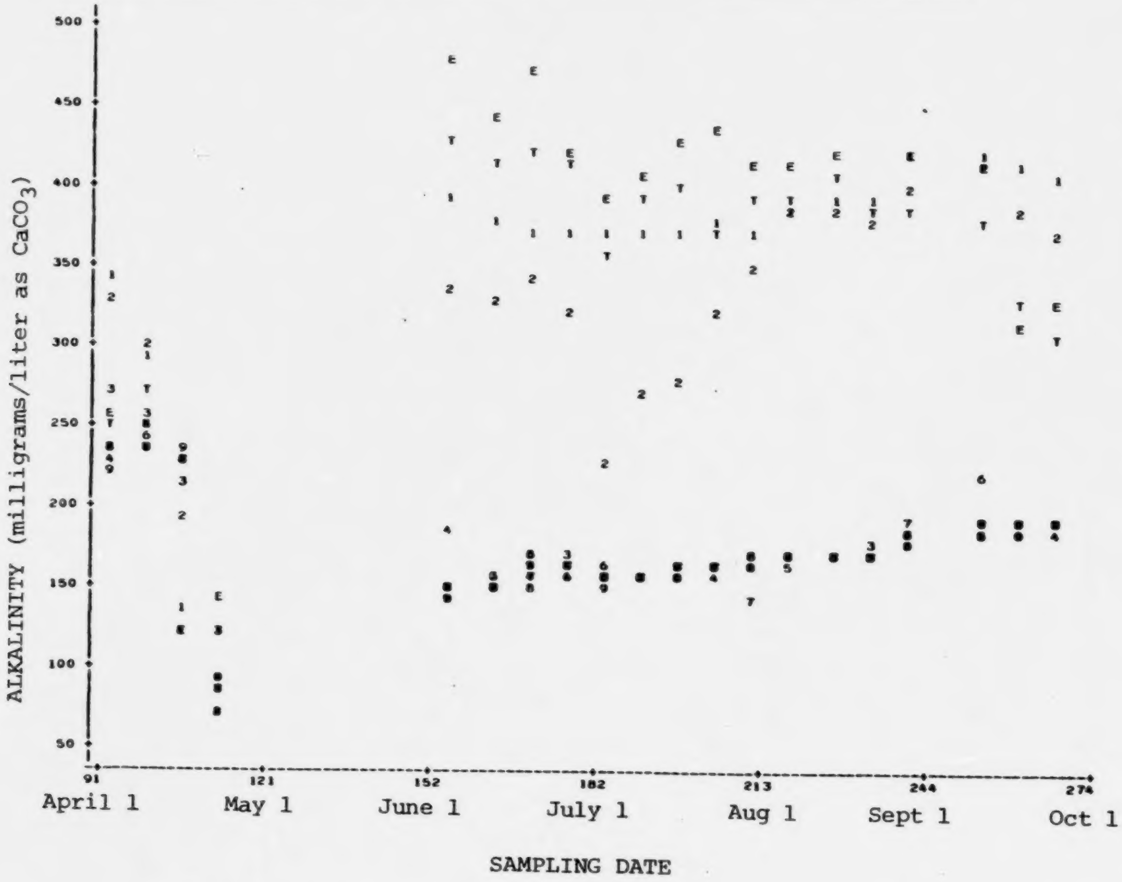

Figure 36. Seasonal and location variations of surface water alkalinity.

MEAN MONTHLY SPECIFIC CONDUCTANCE (microohms/centimeter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	549	1050	1086	1005	1040	1015
2	524	981	1227	1073	1225	1287
Canal:						
9	1319	564	686	866	972	1108
4	1217	563	729	861	991	1103
Lake:						
3	1072	596	738	886	982	1098
5	---	578	726	859	995	1107
6	1246	576	726	859	962	1088
7	1241	573	710	858	970	1120
8	1245	568	698	864	969	1113
Downstream:						
10	520	1193	1227	1193	1132	972
11	540	1250	1342	1237	1175	1017

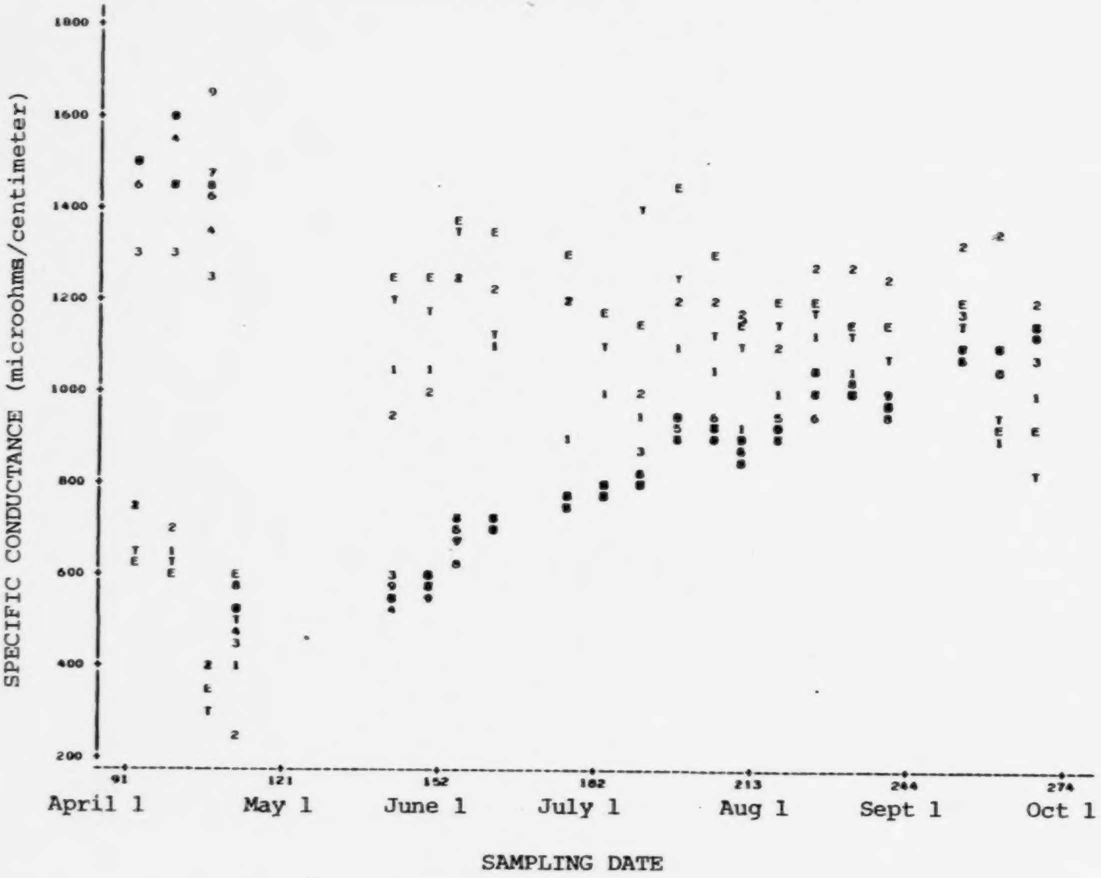

Figure 37. Seasonal and location variations of surface water specific cond~~itions.~~ uctance.

1978 occurred: the initial measurements of the stream sites were smaller than the 1978 measurements and measurements became smaller with each successive week of the April sampling. Whereas, the lake sites displayed a high value (average of 238 milligrams per liter) for the first three weeks in April and dropped sharply during the fourth week (average of 92 milligrams per liter). During the fourth week in April, the lake level rose more than one meter.

Specific conductance (EC) dramatically illustrates the effect of fluctuations in stream flow and lake level (Figure 37). At lake sites in 1978, EC started at about 550 microohms per centimeter and became larger to over 1100 in the fall; whereas, the stream sites remain around 1200 microohms per centimeter throughout 1978 sampling period. During the spring sampling of 1979, EC in the lake sites reached a high of 1600 microohms per centimeter and in stream sites dropped to a low of 240.

4.7.7 Trace Element Data

Data are presented for arsenic, copper, cadmium, chromium, mercury, molybdenum, nickel, lead, selenium, and zinc, Figures 38 through 47, respectively.

4.7.8 Stream Flow

Provisional stream flow data was obtained from the United States Geological Survey (U.S.G.S.), Water Resources Division, Bismarck, MEAN MONTHLY ARSENIC CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	1.6	3.0	1.6	2.0	2.6	1.7
2	1.9	2.5	1.6	2.5	2.3	1.9
Canal:						
9	2.8	2.5	2.1	2.3	3.0	2.8
4	3.2	4.0	2.2	2.5	2.8	2.7
Lake:						
3	4.2	2.0	2.2	2.2	2.8	2.4
5	---	3.0	2.2	2.6	2.8	2.7
6	3.8	3.0	2.1	2.5	3.0	2.7
7	3.1	3.0	2.2	2.4	3.0	2.8
8	3.0	2.5	2.1	2.4	2.8	2.7
Downstream:						
10	1.7	2.5	1.8	2.3	1.9	1.8
11	1.9	2.0	1.7	1.7	1.9	1.7

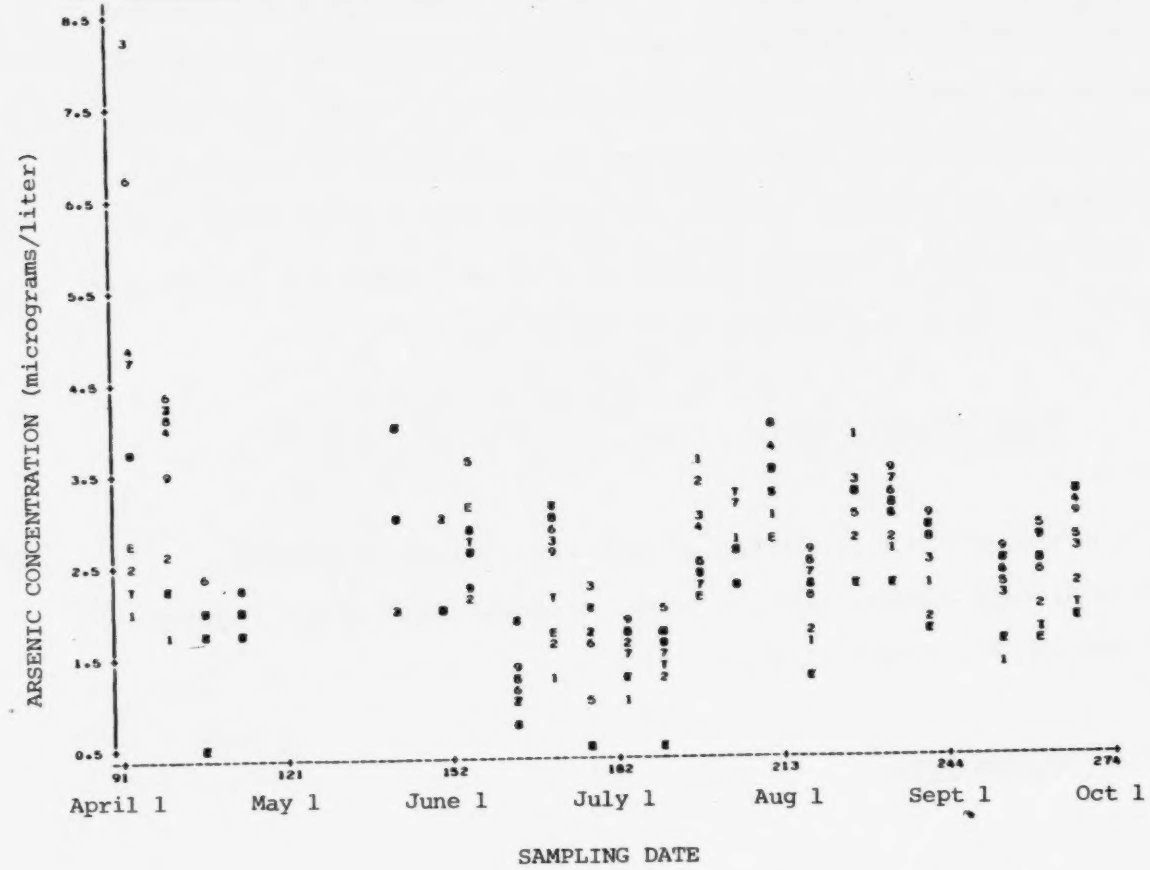

Figure 38. Seasonal and location variations of arsenic in surface water.

MEAN MONTHLY CADMIUM CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	0.18	0.85	0.21	0.16	0.10	0.07
2	0.10	1.00	0.41	0.14	0.13	0.14
Canal:						
9	0.14	0.55	0.40	0.21	0.07	0.17
4	0.17	0.10	0.34	0.15	0.10	0.12
Lake:						
3	0.12	0.70	0.27	0.16	0.11	0.13
5	---	0.65	0.33	0.10	0.11	0.13
6	0.55	1.10	0.34	0.14	0.11	0.13
7	0.13	0.70	0.32	0.14	0.14	0.14
8	0.18	0.65	0.31	0.13	0.12	0.12
Downstream:						
10	0.14	0.60	0.30	0.13	0.09	0.14
11	0.06	0.55	0.33	0.12	0.10	0.35

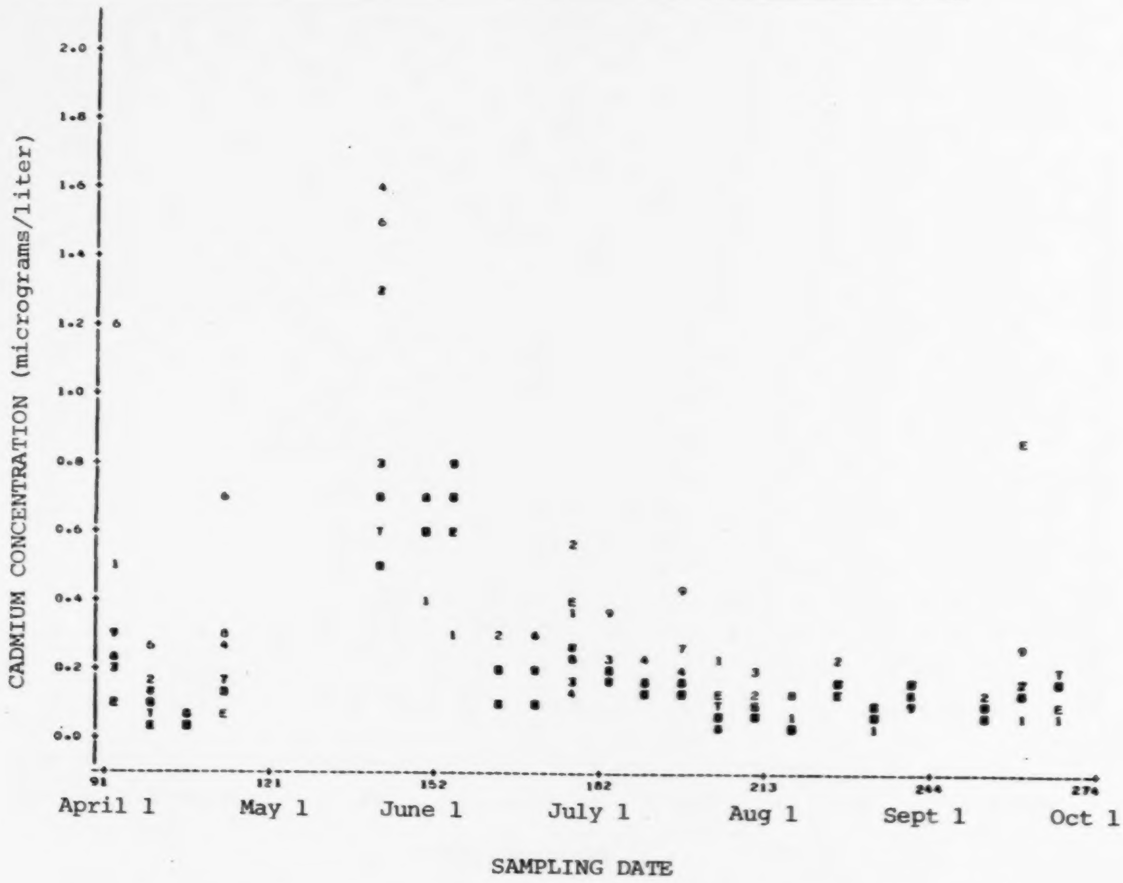

Figure 39. Seasonal and location variations of cadmium in surface water.

MEAN MONTHLY CHROMIUM CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	0.3	0.4	0.8	0.5	0.5	0.6
2	0.3	0.5	0.9	0.3	1.2	0.8
Canal:						
9	0.6	0.7	0.7	0.3	0.4	0.4
4	0.6	0.6	0.7	0.3	0.3	0.4
Lake:						
3	0.6	0.7	0.6	0.3	0.3	0.5
5	---	0.4	0.7	0.3	0.3	0.5
6	0.7	0.6	0.7	0.3	0.4	0.5
7	0.6	0.5	0.6	0.3	0.3	0.4
8	0.7	0.7	0.7	0.3	0.4	0.4
Downstream:						
10	0.3	0.7	0.7	0.3	0.3	0.5
11	0.3	0.7	0.7	0.3	0.3	0.6

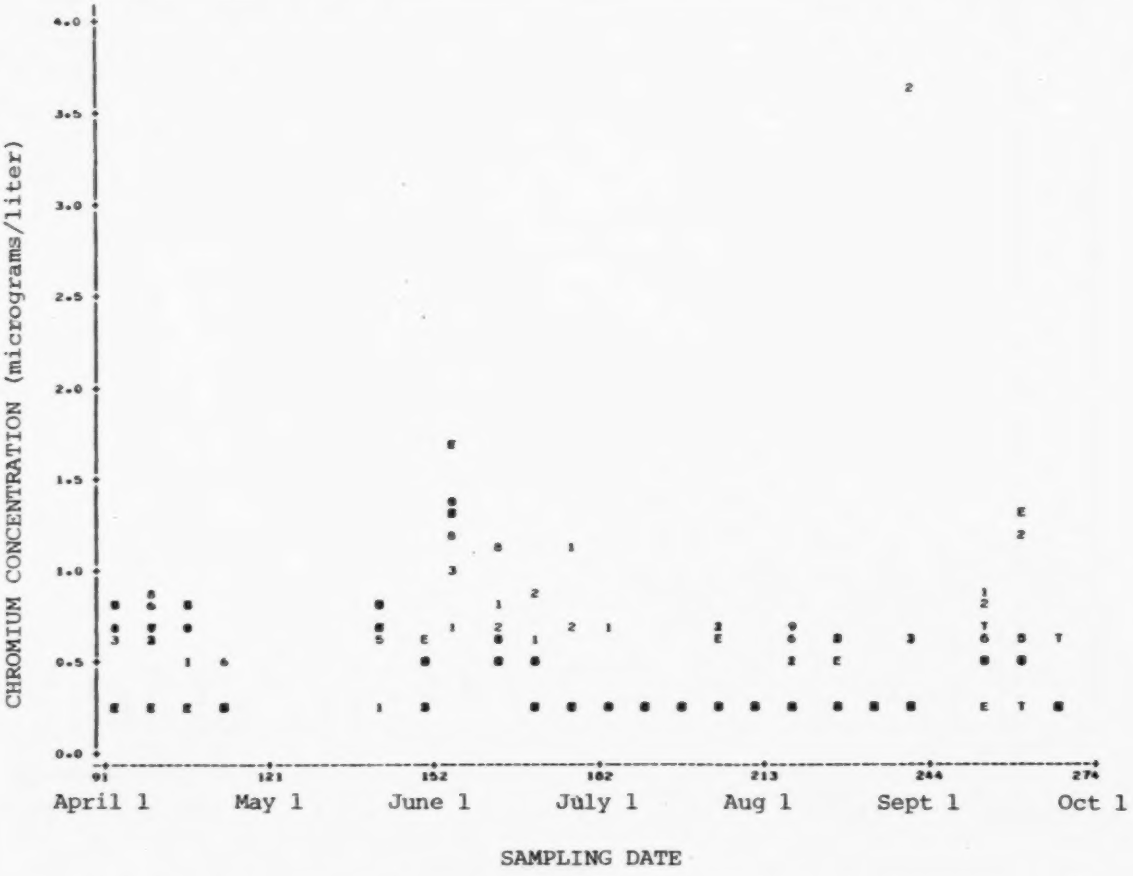

Figure 40. Seasonal and location variations of chromium in surface water.

MEAN MONTHLY COPPER CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	2.1	1.8	3.4	3.6	2.7	1.9
2	1.9	2.9	4.7	4.8	3.1	2.6
Canal:						
9	2.7	2.7	3.5	5.4	3.6	4.0
4	3.0	3.5	4.1	5.6	3.9	3.7
Lake:						
3	2.4	3.3	4.0	5.4	3.7	3.4
5	---	3.3	4.0	6.2	3.7	3.8
6	4.5	3.1	4.1	5.2	3.6	3.7
7	3.0	2.5	3.9	5.0	3.5	3.3
8	3.5	3.1	4.2	5.4	3.3	3.9
Downstream:						
10	1.7	1.8	2.6	3.8	2.5	2.7
11	1.7	2.2	2.9	4.3	3.0	2.8

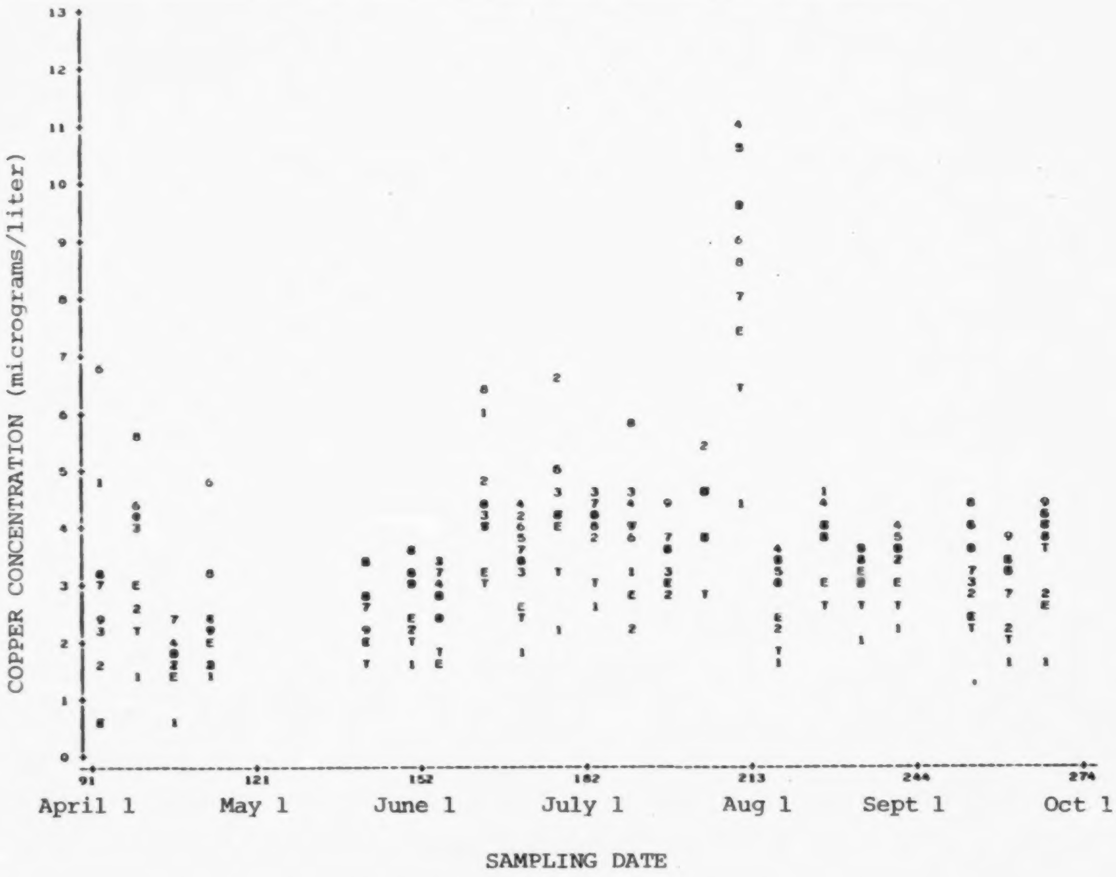

Figure 41. Seasonal and location variations of coppe
in surface water.

MEAN MONTHLY MERCURY CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	0.05	0.34	0.41	0.17	0.11	0.05
2	0.05	0.50	0.31	0.18	0.13	0.05
Canal:						
9	0.08	0.38	1.10	0.20	0.07	0.05
4	0.05	0.78	0.64	0.17	0.63	0.05
Lake:						
3	0.05	0.38	0.31	0.17	0.06	0.05
5	---	0.38	0.25	0.16	0.05	0.05
6	0.05	0.38	0.39	0.21	0.06	0.05
7	0.06	0.38	0.46	0.18	0.06	0.05
8	0.05	0.38	0.40	0.18	0.06	0.05
Downstream:						
10	0.05	0.73	0.25	0.20	0.11	0.05
11	0.05	0.05	0.68	0.20	0.08	0.05

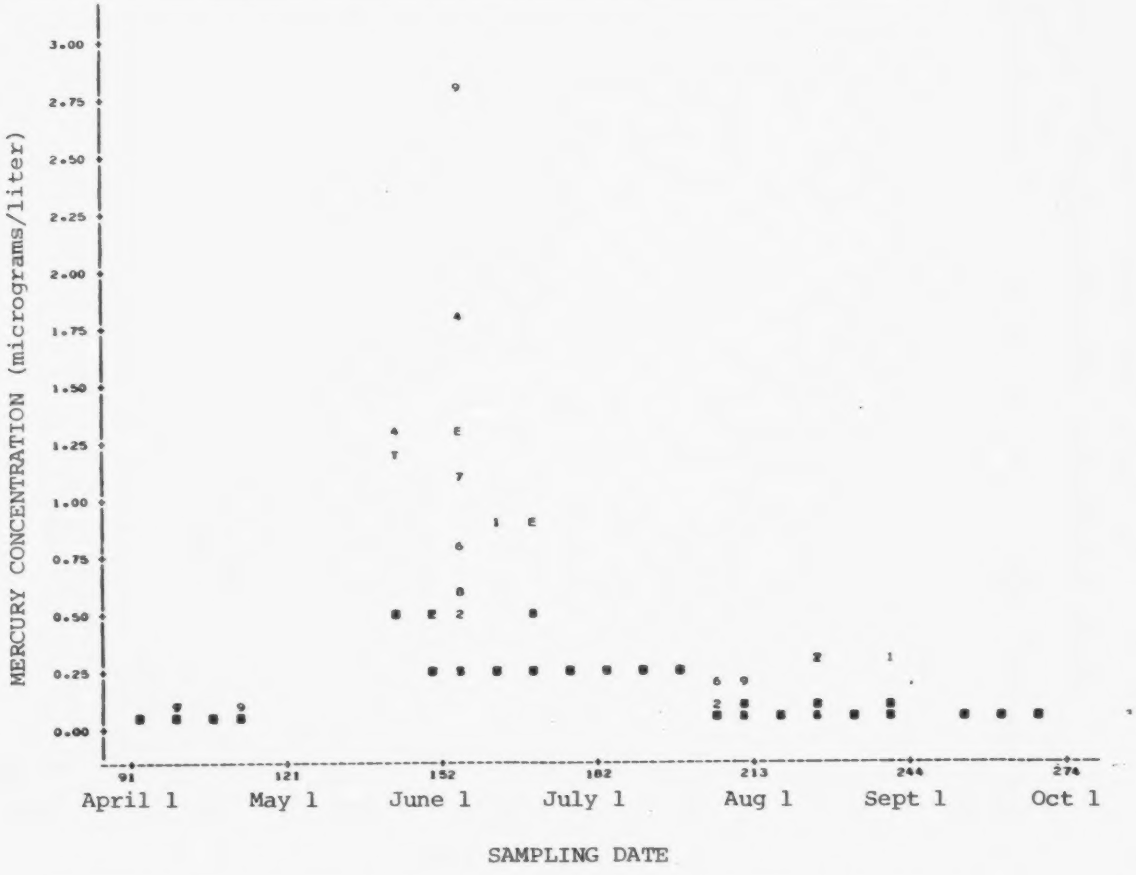

Figure 42. Seasonal and location variations of mercury in surface water.

MEAN MONTHLY MOLYBDENUM CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	1.6	0.7	1.5	2.0	1.9	1.1
2	0.7	0.7	1.0	0.7	1.3	0.1
Canal:						
9	5.3	1.3	4.3	6.8	5.5	6.0
4	7.3	1.1	3.6	6.9	6.1	0.1
Lake:						
3	5.6	0.7	3.6	6.4	5.6	5.6
5	---	0.7	3.9	5.9	5.7	6.5
6	5.4	1.1	4.8	6.9	5.3	0.1
7	7.3	1.2	4.9	6.3	5.7	5.8
8	7.3	2.5	4.9	6.5	5.5	5.6
Downstream:						
10	1.9	1.2	1.7	2.0	1.8	0.7
11	1.6	1.4	1.8	1.8	1.2	0.7

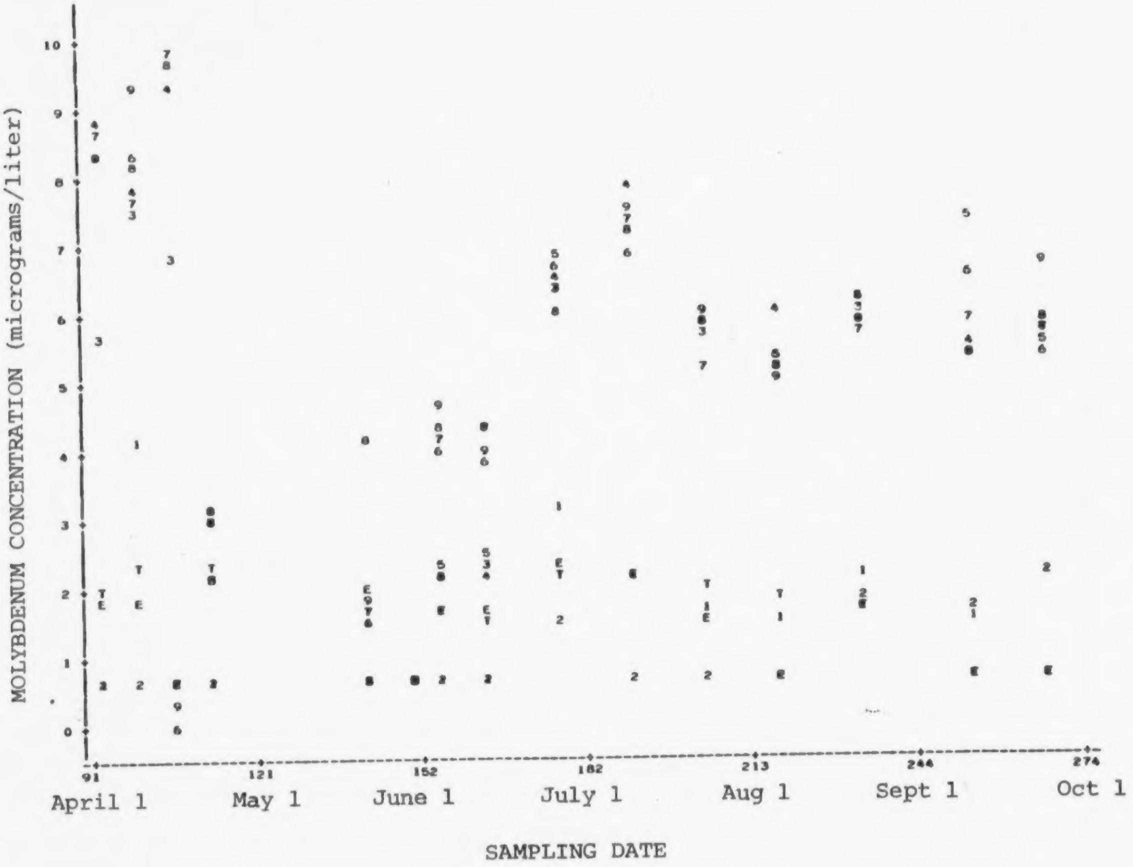

Figure 43. Seasonal and location variations of molybdenum in surface water.

MEAN MONTHLY NICKEL CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	5.4	12.5	12.3	9.1	8.8	0.1
2	5.9	13.5	16.2	12.2	13.2	12.2
Canal:						
9	16.9	16.0	8.2	9.3	10.6	11.6
4	18.9	13.5	8.8	9.3	9.5	11.5
Lake:						
3	17.0	13.0	9.0	9.9	10.4	11.4
5	---	16.5	8.8	9.3	9.8	11.7
6	18.9	11.0	9.2	9.0	9.5	11.8
7	17.6	13.0	10.5	9.3	10.4	11.7
8	17.0	16.0	12.1	9.4	10.2	12.6
Downstream:						
10	5.3	25.5	16.6	14.4	13.8	12.3
11	5.8	22.5	17.7	13.2	14.0	12.8

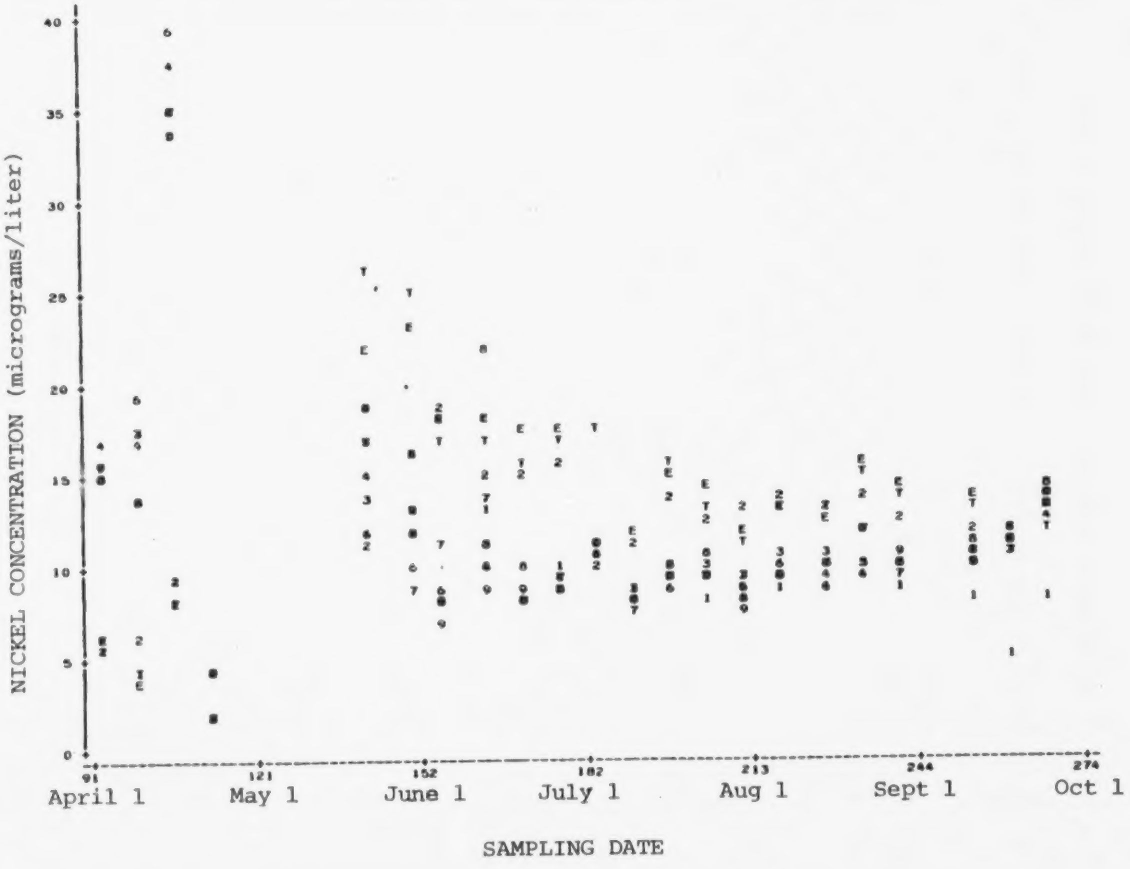

Figure 44. Seasonal and location variations of nickel in surface water.

MEAN MONTHLY LEAD CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	0.5	1.1	1.1	0.6	0.9	0.7
2	0.5	2.5	1.6	0.7	1.0	0.9
Canal:						
9	0.5	1.3	0.9	0.5	0.8	0.8
4	0.5	1.8	0.9	0.5	0.7	0.8
Lake:						
3	0.6	1.8	1.0	0.6	0.7	0.9
5	---	1.3	0.9	0.5	0.7	0.8
6	0.5	3.7	0.9	0.5	0.7	0.8
7	0.6	1.6	1.2	0.5	0.7	0.7
8	0.6	1.6	1.5	0.5	0.5	0.8
Downstream:						
10	0.5	4.9	1.2	1.0	0.7	1.2
11	0.5	2.9	1.3	0.7	0.7	0.7

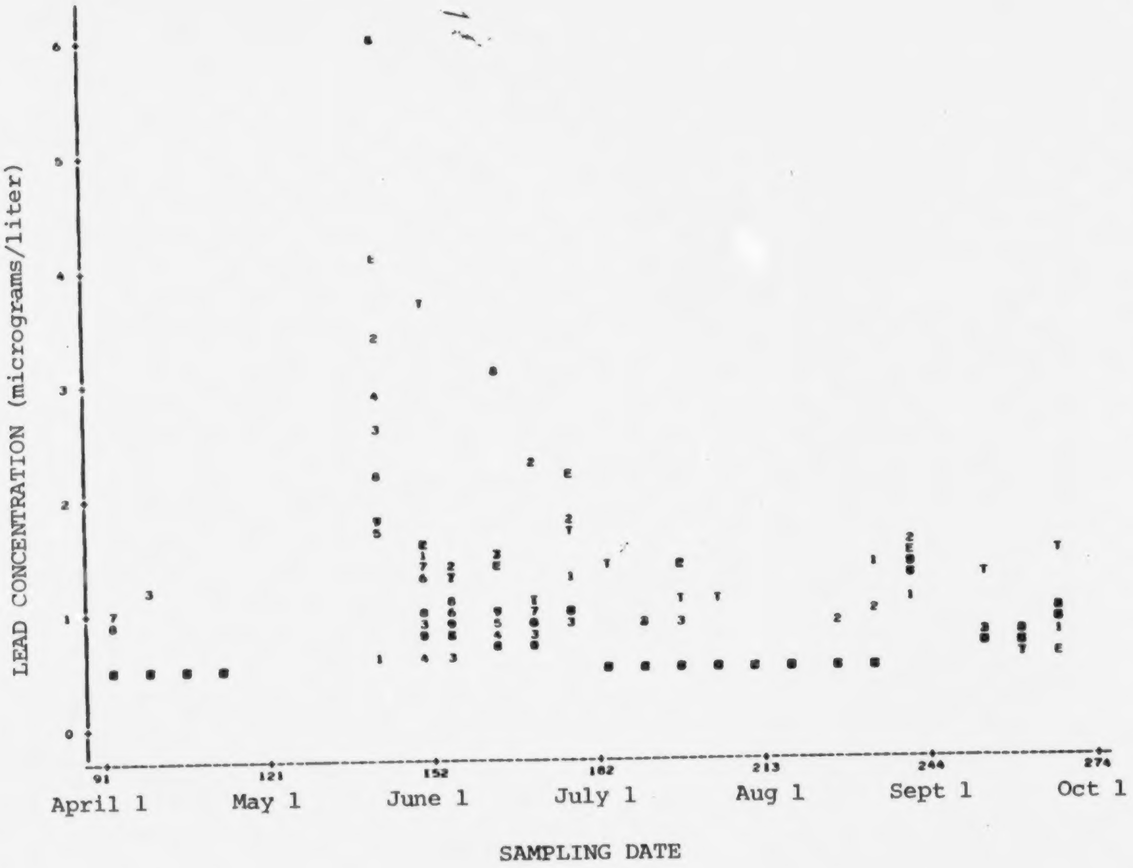

Figure 45. Seasonal and location variations of lead in surface water.

MEAN MONTHLY SELENIUM CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	1.3	18.7	25.3	14.2	2.4	3.3
2	1.0	15.5	25.7	11.3	2.4	3.8
Canal:						
9	2.7	13.9	15.2	11.0	1.0	3.5
4	2.5	12.0	19.1	11.5	2.1	2.8
Lake:						
3	2.6	6.6	19.6	10.2	1.5	2.5
5	---	12.9	20.1	4.4	1.8	2.8
6	3.2	12.7	18.1	10.8	1.9	3.3
7	3.1	14.0	18.9	10.3	1.4	3.0
8	2.8	13.4	18.6	10.9	1.0	2.3
Downstream:						
10	1.0	23.4	26.8	20.0	2.4	4.3
11	1.0	27.9	32.7	9.3	2.4	3.5

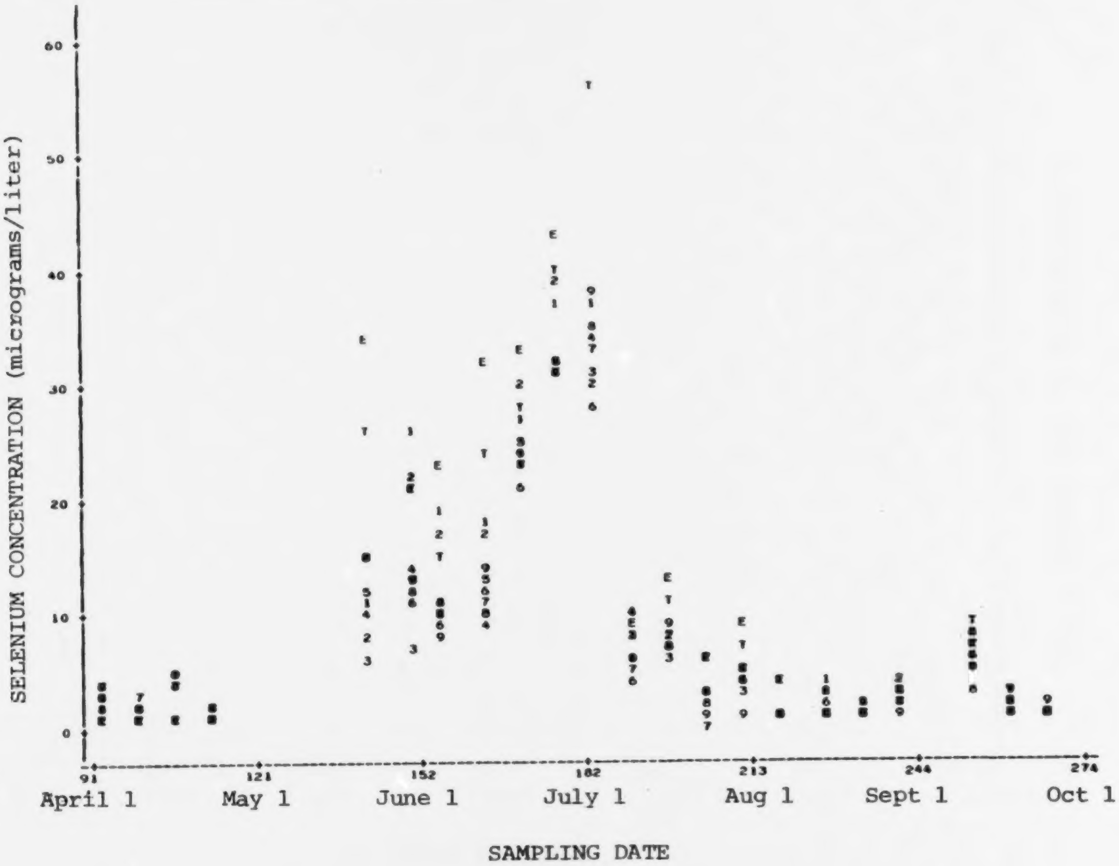

Figure 46. Seasonal and location variations of selenium in surface water.

MEAN MONTHLY ZINC CONCENTRATION (micrograms/liter)

Site Number	April	May	June	July	August	Sept
Upstream:						
1	2.2	---	13.3	3.2	1.2	0.3
2	1.5	---	16.3	1.9	1.7	0.3
Canal:						
9	0.5	---	12.5	1.7	1.4	0.6
4	0.6	---	14.8	2.0	0.9	0.5
Lake:						
3	0.6	---	12.3	1.8	0.9	0.4
5	---	---	7.3	1.2	1.2	0.5
6	0.9	---	9.8	1.7	1.4	0.5
7	0.5	---	4.5	3.0	0.5	0.3
8	0.7	---	7.0	1.6	1.0	0.7
Downstream:						
10	0.7	---	7.3	1.1	1.0	0.6
11	0.7	---	7.0	1.3	1.1	0.5

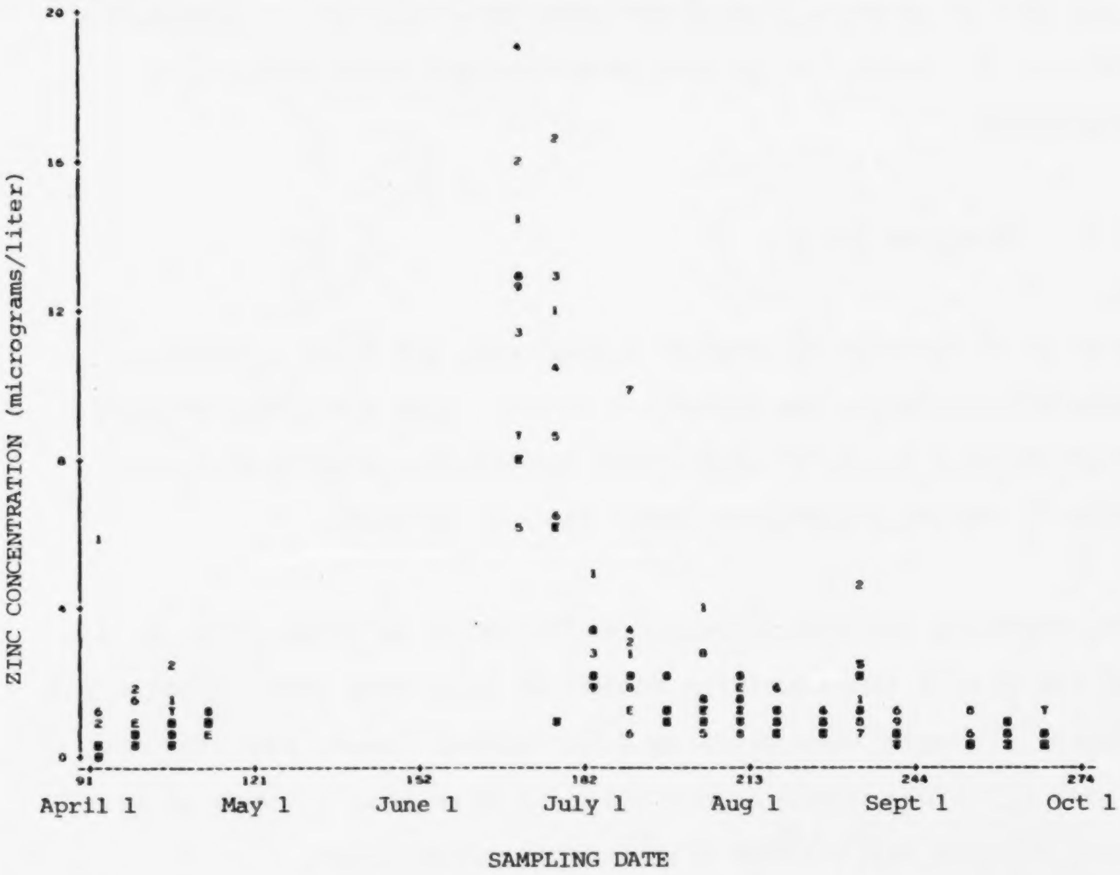

Figure 47. Seasonal and location variations of zinc in surface water.

North Dakota. U.S.G.S. gauging stations are located on Square Butte Creek and Hagel Creek near sites 1 and 2, respectively. Figures 48 and 49 depict the square-root of daily stream flow data from May-September 1978.

The daily average streamflow in both creeks has been correlated to the water parameters measured at sampling sites 1 and 2. The correlation coefficients are shown in Table 26. Stream concentrations of cadmium, chromium, and selenium are significantly correlated with streamflow in both creeks. Concentrations of these elements increase in streamflow as streamflow volume increases due to watershed drainage from summertime rainstorms.

4.8 Sediment Data

Tables 27 through 36 present extractable and total elemental concentrations in the sediments by site with the corresponding mean surface water concentration and distribution coefficient. Site 9, having a concrete base, was not sampled.

In comparing the distribution coefficients of sites 2, 3, 5, 6, 7, and 8 with the remaining sites, it was found that chromium and copper are more than twice as high; nickel, lead, and zinc are about 1.5 times greater; and selenium more than 5 times as high. Only cadmium has a lower distribution coefficient.

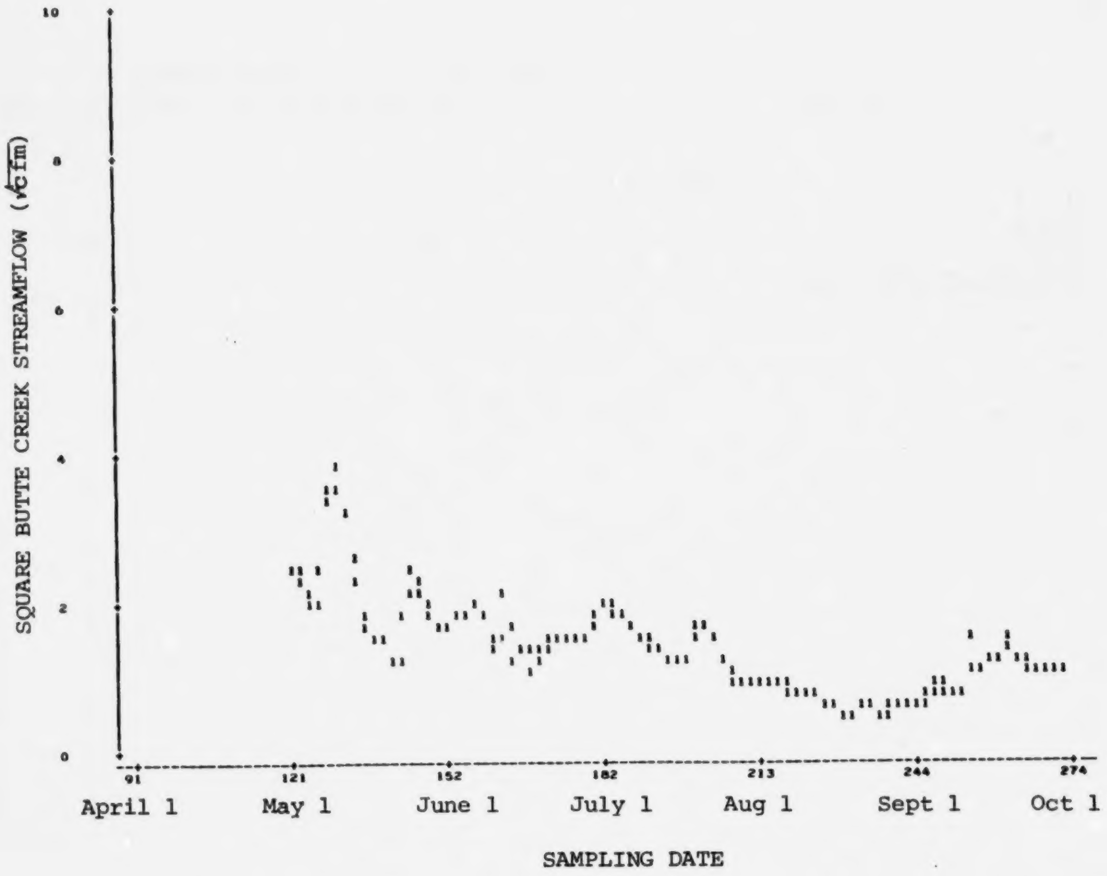

Figure 48. Streamflow measured by a U.S.G.S. gasing station on Square Butte Creek at water sampling site 1.

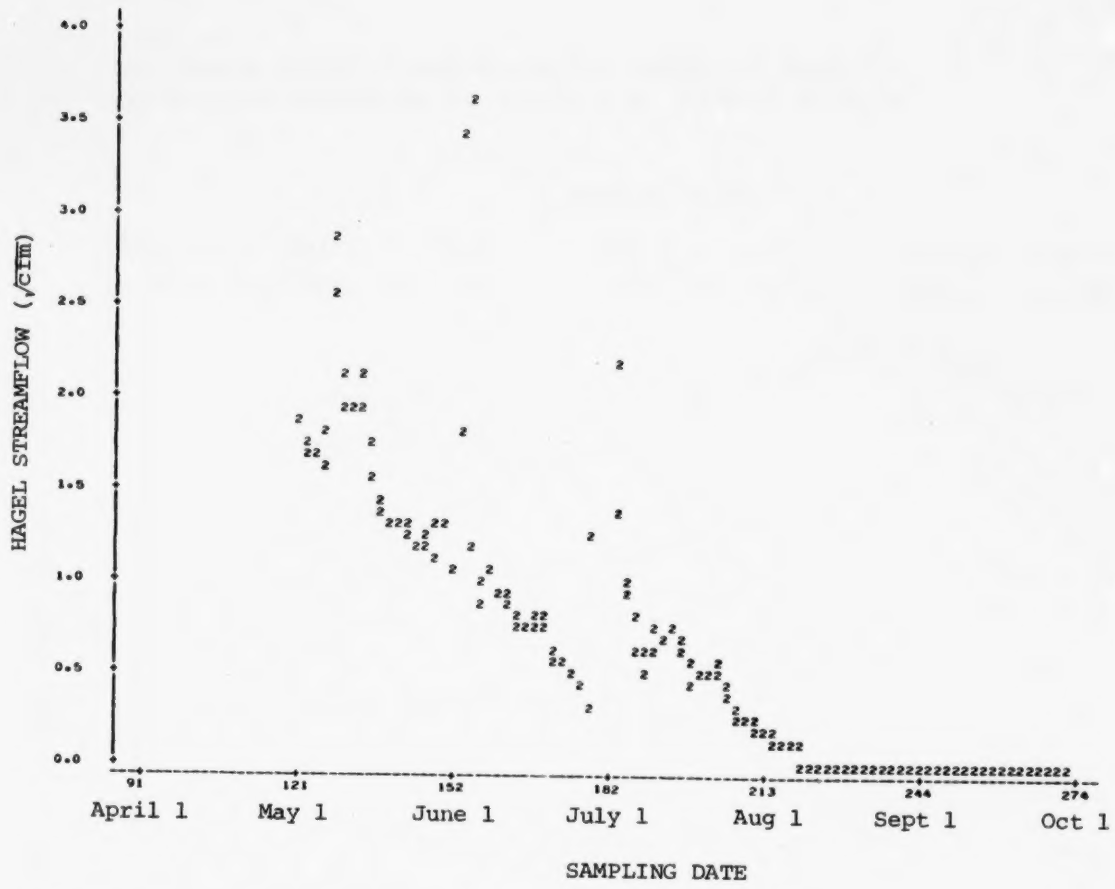

Figure 49. Streamflow measured by a U.S.G.S. gasing station on Hagel Creek at water sampling site 2.

TABLE 26

CORRELATION BETWEEN STREAM FLOW AND MEASURED WATER PARAMETERS

<table>
<tr><th></th><th colspan="2">Correlation Coefficient (R)/P>|R|[1]</th></tr>
<tr><th>Parameter</th><th>Square Butte Creek</th><th>Hagel Creek</th></tr>
<tr><td>Temperature</td><td>-0.05/0.86</td><td>0.23/0.37</td></tr>
<tr><td>Alkalinity</td><td>-0.28/0.28</td><td>-0.73/<0.01</td></tr>
<tr><td>Specific Conductivity</td><td>0.18/0.50</td><td>-0.74/<0.01</td></tr>
<tr><td>Dissolved Oxygen</td><td>-0.19/0.49</td><td>0.66/<0.01</td></tr>
<tr><td>pH</td><td>-0.25/0.34</td><td>0.03/0.92</td></tr>
<tr><td>Arsenic</td><td>-0.43/0.09</td><td>-0.14/0.57</td></tr>
<tr><td>Copper</td><td>0.34/0.20</td><td>0.17/0.49</td></tr>
<tr><td>Cadmium</td><td>0.50/0.05</td><td>0.67/<0.01</td></tr>
<tr><td>Chromium</td><td>0.37/0.16</td><td>-0.17/0.51</td></tr>
<tr><td>Mercury</td><td>0.72/<0.01</td><td>0.81/<0.01</td></tr>
<tr><td>Molybdenum</td><td>-0.41/0.24</td><td>-0.61/0.05</td></tr>
<tr><td>Nickel</td><td>0.60/0.01</td><td>0.11/0.65</td></tr>
<tr><td>Lead</td><td>0.09/0.74</td><td>0.39/0.11</td></tr>
<tr><td>Selenium</td><td>0.63/0.01</td><td>0.51/0.03</td></tr>
<tr><td>Zinc</td><td>0.37/0.22</td><td>0.19/0.52</td></tr>
</table>

---

[1] P>|R| is probability of greater absolute value of the correlation coefficient.

TABLE 27

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 1

Element	Sediment(µg/g) [1] Extractable	Total	Surface Water(µg/l) April-September Mean/std-dev	Distribution Coefficient [2]
Cadmium (Cd)	0.19	<1 (0.5)	0.21 / 0.28	2,380
Chromium (Cr)	0.18	25	0.5 / 0.3	50,000
Copper (Cu)	2.26	11	2.7 / 1.4	4,070
Molybdenum (Mo)	0.07	<3 (1.5)	1.5 / 1.1	1,000
Nickel (Ni)	1.46	17	9.0 / 3.4	1,890
Lead (Pb)	2.12	23	0.8 / 0.4	28,800
Sulfur (S)	71	1,125		
Selenium (Se)	0.005	0.26	10.5 /12.0	24.8
Zinc (Zn)	1.89	48	3.2 / 4.2	15,000

---

[1] A < indicates concentration was less than minimum detectable level. One-half of the detectable level is shown in parenthesis.

[2] Sediment total concentration divided by the mean surface water concentration.

TABLE 28

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 2

Element	Sediment(µg/g) [1] Extractable	Total	Surface Water(µg/l) April-September Mean/std-dev	Distribution Coefficient [2]
Cadmium	0.14	<1 (0.5)	0.26 / 0.29	1,920
Chromium	0.21	41	0.7 / 1.9	58,600
Copper	5.80	24	3.5 / 1.9	6,860
Molybdenum	0.15	<3 (1.5)	1.0 / 1.05	1,500
Nickel	3.08	35	12.1 / 3.7	2,890
Lead	3.02	30	1.1 / 0.7	27,300
Sulfur	424	5,100		
Selenium	0.002	1.23	9.8 /11.2	126
Zinc	5.95	96	3.1 / 4.9	31,000

TABLE 29

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 3

Element	Sediment(µg/g) 1/		Surface Water(µg/l) April-September	Distribution Coefficient 2/
	Extractable	Total	Mean/std-dev	
Cadmium	0.22	<1 (0.5)	0.21 / 0.21	2,380
Chromium	0.20	57	0.4 / 0.2	142,500
Copper	6.48	26	3.8 / 1.7	6,840
Molybdenum	0.37	13	4.6 / 2.4	2,830
Nickel	3.18	29	11.6 / 5.8	2,500
Lead	3.92	34	0.8 / 0.5	42,500
Sulfur	292	3,840		
Selenium	0.006	0.87	7.6 / 9.4	115
Zinc	7.48	90	2.2 / 3.7	40,900

TABLE 30

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 4

Element	Sediment(µg/g) 1/		Surface Water(µg/l) April-September	Distribution Coefficient 2/
	Extractable	Total	Mean/std-dev	
Cadmium	0.05	<1 (0.5)	0.26 / 0.34	1,920
Chromium	0.10	27	0.4 / 0.3	67,500
Copper	1.82	12	4.1 / 1.7	2,930
Molybdenum	0.04	<3 (1.5)	5.3 / 2.8	283
Nickel	0.41	20	11.7 / 6.4	1,710
Lead	1.47	12	0.7 / 0.5	17,100
Sulfur	41	105		
Selenium	0.005	0.22	8.4 / 9.7	26.2
Zinc	1.02	42	2.6 / 4.7	16,200

TABLE 31

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 5

Element	Sediment(μg/g) Extractable	Total 1/	Surface Water(μg/l) April-September Mean/std-dev	Distribution Coefficient 2/
Cadmium	0.17	<1 (0.5)	0.23 / 0.24	2,170
Chromium	0.17	48	0.4 / 0.3	120,000
Copper	7.58	27	4.2 / 1.8	6,430
Molybdenum	0.13	<3 (1.5)	4.3 / 2.5	349
Nickel	1.97	27	10.7 / 2.6	2,520
Lead	3.88	16	0.8 / 0.4	20,000
Sulfur	139	1,245		
Selenium	0.011	0.67	8.4 / 9.1	79.8
Zinc	5.14	26	2.0 / 2.6	13,000

TABLE 32

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 6

Element	Sediment(μg/g) Extractable	Total 1/	Surface Water(μg/l) April-September Mean/std-dev	Distribution Coefficient 2/
Cadmium	0.21	<1 (0.5)	0.35 / 0.40	1,430
Chromium	0.30	63	0.5 / 0.3	126,000
Copper	17.1	42	4.2 / 1.5	10,000
Molybdenum	0.24	<3 (1.5)	4.8 / 3.0	313
Nickel	3.37	34	11.7 / 7.3	2,910
Lead	8.08	23	1.0 / 1.2	23,000
Sulfur	218	1,450		
Selenium	0.008	0.81	8.5 / 8.9	95.3
Zinc	4.9	105	2.2 / 3.2	47,700

TABLE 33

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 7

Element	Sediment(µg/g) 1/		Surface Water(µg/l) April-September	Distribution Coefficient 2/
	Extractable	Total	Mean/std-dev	
Cadmium	0.22	<1 (0.5)	0.22 / 0.22	2,270
Chromium	0.40	64	0.4 / 0.3	160,000
Copper	19.2	48	3.7 / 1.2	13,000
Molybdenum	0.58	<3 (1.5)	5.4 / 2.6	278
Nickel	5.12	39	12.0 / 6.3	3,250
Lead	8.56	24	0.8 / 0.4	30,000
Sulfur	638	1,153		
Selenium	0.010	1.50	8.6 / 9.7	174
Zinc	6.21	117	1.7 / 2.8	68,800

TABLE 34

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 8

Element	Sediment(µg/g) 1/		Surface Water(µg/l) April-September	Distribution Coefficient 2/
	Extractable	Total	Mean/std-dev	
Cadmium	0.22	<1 (0.5)	0.22 / 0.20	2,270
Chromium	0.24	64	0.5 / 0.3	128,000
Copper	12.0	41	4.1 / 1.5	10,000
Molybdenum	0.61	<3 (1.5)	5.6 / 2.2	268
Nickel	2.60	35	12.6 / 6.4	2,780
Lead	5.96	20	0.8 / 0.7	2,500
Sulfur	518	1,830		
Selenium	0.006	1.04	8.4 /10.0	124
Zinc	6.79	106	1.8 / 3.0	58,900

TABLE 35

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 10

Element	Sediment(μg/g) Extractable	Total 1/	Surface Water(μg/l) April-September Mean/std-dev	Distribution Coefficient 2/
Cadmium	0.03	<1 (0.5)	0.20 / 0.19	2,500
Chromium	0.07	14	0.4 / 0.3	35,000
Copper	1.52	8	2.6 / 1.1	3,080
Molybdenum	0.03	<3 (1.5)	1.6 / 0.6	938
Nickel	0.42	16	13.7 / 5.7	1,170
Lead	1.19	11	1.3 / 1.3	8,460
Sulfur	37	300		
Selenium	0.008	0.16	12.4 /15.0	12.9
Zinc	1.66	40	1.6 / 2.2	25,000

TABLE 36

CONCENTRATION OF TRACE ELEMENTS IN SEDIMENTS AND SURFACE WATER - SITE 11

Element	Sediment(μg/g) Extractable	Total 1/	Surface Water(μg/l) April-September Mean/std-dev	Distribution Coefficient 2/
Cadmium	0.04	<1 (0.5)	0.22 / 0.23	2,270
Chromium	0.10	35	0.5 / 0.4	70,000
Copper	1.44	14	2.9 / 1.3	4,830
Molybdenum	0.09	<3 (1.5)	1.5 / 0.6	1,000
Nickel	0.42	37	13.6 / 5.0	2,720
Lead	0.94	21	1.0 / 0.9	21,000
Sulfur	36	405		
Selenium	0.006	0.30	11.8 /13.5	25.4
Zinc	1.50	60	1.6 / 2.1	37,500

Sites 1, 4, 10, and 11 had medium to coarse sand sediments: the remaining sites had sediments consisting mainly of coarse clay. Although organic content and humic compounds were not determined, it was assumed that the coarse clay sites were high in these two constituents. This assumption is exemplified by the summary data in Table 37 which compares the average for sites 2, 3, 5, 6, 7 and 8 versus sites 1, 4, 10 and 11.

As the data in Table 37 dramatically illustrates, the clay sediments have greater concentrations for every element.

4.9 Soils Data

4.9.1 Surface Soils Characteristics

The soil characteristics of color, texture, and structure for the top 15 centimeters of each of the 64 sampling plots were determined. The texture and structure characteristics were evaluated in terms used in the U.S. Department of Agriculture soil taxonomic system (25). The color characteristic was based upon the Munsell color charts used in that system: all colors were determined for the moist soil condition.

The soil structure of the surface horizon in native sod, on which nearly all the plots were located, was weak coarse prismatic on loamy to clayey soils without a shallow sodic horizon. The structure, texture, and color definition of each of the eight types which were observed are presented in Appendix D.

TABLE 37

MEAN ELEMENTAL CONCENTRATION IN SEDIMENTS ($\mu g/g$)

	Extractable		Total	
Element	Coarse Sand	Coarse Clay	Coarse Sand	Coarse Clay
Cadmium	0.08	0.20	1	1
Chromium	0.11	0.25	25.3	56.2
Copper	1.76	11.4	11.3	34.7
Molybdenum	0.06	0.35	< 3	< 3 1/
Nickel	0.68	3.22	22.5	33.2
Lead	1.43	5.57	16.8	24.5
Sulfur	46.3	372	484	2436
Selenium	0.006	0.007	0.24	1.02
Zinc	1.52	6.08	47.5	98.3

1/ Site 3 had a molybdenum concentration of 13 micrograms per gram while the remaining sites were less than (<) 3.

A map of the surface soil characteristics for the 64 sampling plots is given in Figure 50. A majority of the surface soils were very dark brown and very dark grayish brown loams with weak to moderate coarse and medium subangular blocky structure separating into weak to moderate crumb and granular structure.

4.9.2 Soils Classification

A soil classification survey of Oliver County has been completed (26). Since sampling sites may vary geochemically from this survey, a soil classification study was completed for some plots.

The soil classifications of 28 soil plots are shown in Table 38. These plots contained a variety of soil classifications subgroups and series. Ten plots were of the Williams series within the Typic Argiborolis subgroup, five of the Zahl series within the Entic Haploborolls subgroup, and four of the Arnegard series in the Pachic Haploborolls subgroup. The remaining plots were each from separate classifications. Thus, the soil and vegetation samples were obtained from plots having diverse geophysical structures.

4.9.3 Limitation of Data Set

The surface soil samples (top 1.3-cm layer soil) were collected at only 20 of the 64 field soil and vegetation plots. The 10-cm soil samples collected at all 64 plots included the top 1.3-cm layer of soil.

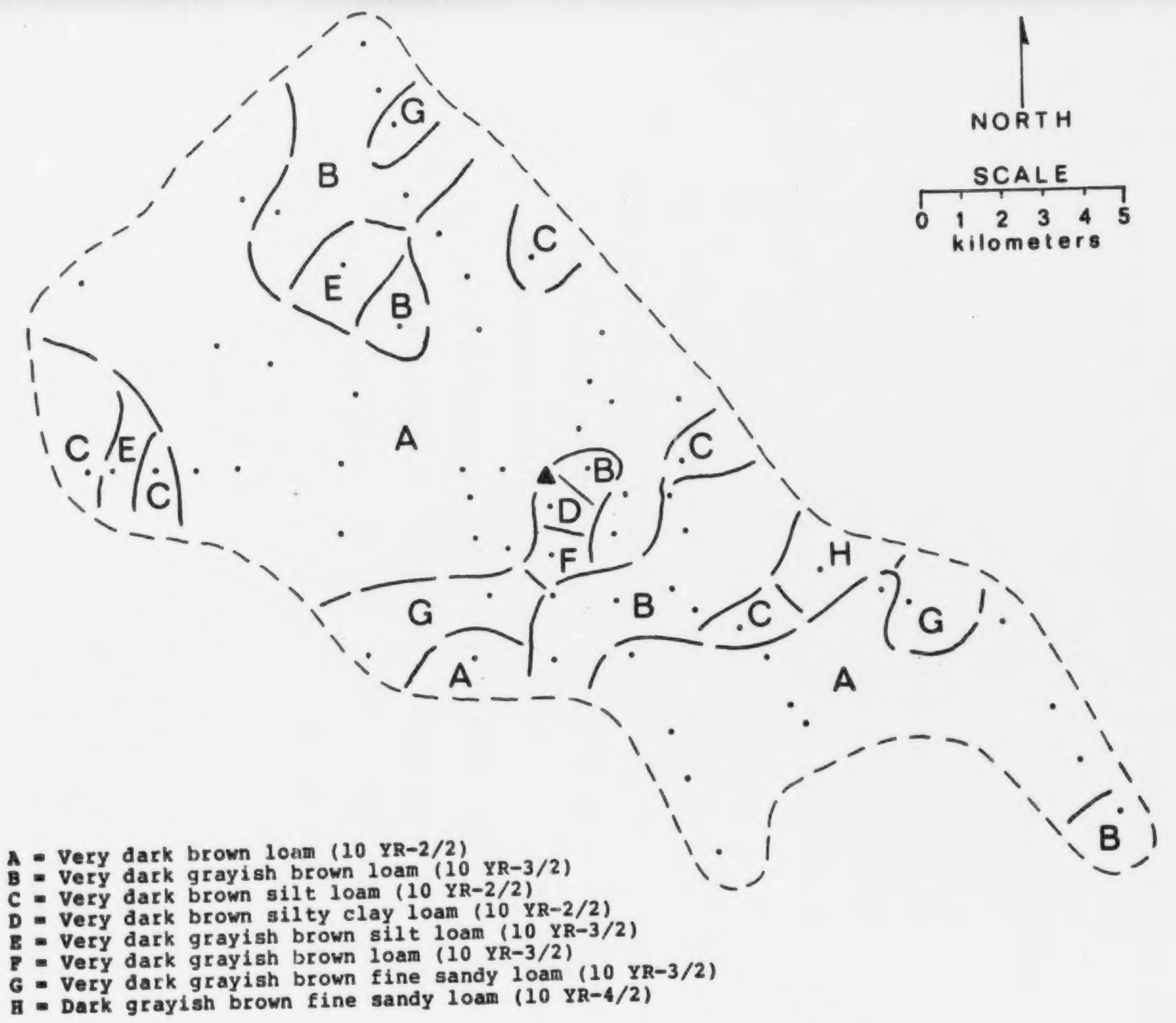
NORTH
SCALE
0 1 2 3 4 5
kilometers
A
B
C
D
E
F
G
H
A = Very dark brown loam (10 YR-2/2)
B = Very dark grayish brown loam (10 YR-3/2)
C = Very dark brown silt loam (10 YR-2/2)
D = Very dark brown silty clay loam (10 YR-2/2)
E = Very dark grayish brown silt loam (10 YR-3/2)
F = Very dark grayish brown loam (10 YR-3/2)
G = Very dark grayish brown fine sandy loam (10 YR-3/2)
H = Dark grayish brown fine sandy loam (10 YR-4/2)

Figure 50. Map of soil characteristics for the top 15 centimeters of each of the 64 sampling plots.

TABLE 38

SOIL CLASSIFICATION OF 28 PLOTS CORED TO A DEPTH OF 91 CENTIMETERS

Order	Suborder	Great Groups	Subgroups	Series	Family	Plot Numbers
Entisols	Orthents	Ustorothents	Typic Ustorthents	Cabba	loamy, mixed (calcerous)	32[1/]
Mollisols	Borolls	Haploborolls	Typic Haloborolls	Amor	fine loamy, mixed	47[2/]
				Vebar	coarse loamy, mixed	29
				Sen	fine silty, mixed	19[3/]
"	"	"	Pachic Haploborolls	Arnegard	fine loamy, mixed	18[4/], 34(2), 38(2), 52
				Grassna	fine silty, mixed	54[5/]
				Mandan	coarse silty, mixed	17
				Parshall	coarse loamy, mixed	25
"	"	"	Typic Argiborolls	Regent	fine, montmorillonitic	35[6/]
				Williams	fine loamy, mixed	5, 8, 13, 14, 23 27, 31, 34(1), 37[7/] 38(1)
"	"	"	Leptic Natriborolls	Rhoades	fine, montmorillonitic	33
			Cumulic Haploborolls	Straw	fine loamy, mixed	12
"	"	"	Entic Haploborolls	Werner	loamy, mixed shallow	60
				Zahl	fine loamy, mixed	1, 2, 7, 20, 28

1/ Loamy soft bedrock at slight greater depths than the range for the Cabba series.
2/ Relatively unweathered soft bedrock is at slightly greater depths than the range for the Amor series.
3/ Calcerous at slightly shallower depths than the range for the Sen series.
4/ Calcerous at much shallower depths than the range for the Arnegard series.
5/ The C horizon is heavier textured than the range for the Grassna series and appears to be formed in glacial reworked, highly weathered soft bedrock of the Fort Union formation.
6/ Loam texture in the surface horizon is coarser than the range for the Regent series.
7/ The lower part of the B horizon and C horizon are formed in highly weathered stratified soft residual bedrock while the range of the Williams series has the soil formed in glacial till to depths of more than 40 inches.

The organic matter content and cation-exchange capacity (CEC) were not determined for the soil samples, due to project constraints.

4.9.4 Element Concentrations

The arithmetic mean and standard deviation of extractable and total element concentrations for the 10-cm soil samples are listed in Table 39. The extractable concentration is that portion of the total concentration generally considered available for plant uptake, depending among other things on the chemical extractant of the laboratory analysis method (27).

The coefficient of variation, shown in Table 39, is a measure of the plot-to-plot variability of the element. Total concentrations of aluminum, potassium, and titanium had the lowest variability within the 64 plots.

4.9.5 Surface Accumulation

Elements, which are taken up through the root system into above ground portions of vegetation, are released back to the soil upon decay of dead vegetative matter. Many of these elements are chemically bonded to the organic matter and, therefore, are not leached downward through the soil (28). Deposition of elements directly onto the soil, onto leaf surfaces, and leaf absorption of the elements should result in long-term enrichment of the surface layer of soil.

TABLE 39

ELEMENT CONCENTRATIONS FOR 64 10-CM SOIL SAMPLES (μg/g)

	Extractable		Total	
Element	mean	std-dev/CV[1/]	mean	std-dev/CV
Cadmium (Cd)	0.09	0.03/36	0.5	0.0/0
Chromium (Cr)	0.03	0.01/43	49.0	9.3/19
Copper (Cu)	0.74	0.29/39	18.8	5.5/30
Lead (Pb)	0.89	0.27/30	14.6	6.2/42
Molybdenum (Mo)	0.08	0.05/60	1.5	0.0/0
Nickel (Ni)	1.04	0.41/39	25.8	8.76/34
Selenium (Se)	0.007	0.003/44	0.56	0.17/29
Sulfur (S)	1.1	0.8/69	332	90/27
Zinc (Zn)	2.1	1.7/82	74	15/20
Aluminum (Al)			53,760	6,160/11
Calcium (Ca)			11,990	10,390/87
Iron (Fe)			22,880	3,930/17
Potassium (K)			16,660	1,770/11
Magnesium (Mg)			6,810	2,770/41
Manganese (Mn)			471.6	123.8/26
Sodium (Na)			10,550	1,720/16
Titanium (Ti)			2,960	330/11

[1/] mean = arithmetic mean, std-dev = standard deviation of concentrations, CV = coefficient of variation which is (std-dev/mean) x 100.

The concentrations of elements from 20 surface soil samples, 1.3 centimeters deep, are given in Table 40. The locations of these sites were shown in Figure 13. The concentrations of elements for the corresponding 10-cm samples are also shown in this table. The averages of ratios of concentrations between the two sampling depths are given in Table 41.

The Mann-Whitney rank test was applied to the distributions of extractable and total concentrations for each element. The test statistic (Z) and the probability of obtaining a larger absolute value if Z for a sample size of 20 are also shown in Table 41.

Extractable concentrations of cadmium, chromium, lead, and zinc were significantly larger in the 1.3-cm soil samples. Similarly, total concentrations of lead, zinc, and manganese were significantly larger in the 1.3-cm samples.

The extractable concentrations of elements in soils are not in direct proportion to the total concentrations revealed by low correlation coefficients for all elements except copper, Table 42. Therefore, the choice of extractable or total concentration in statistical analysis must depend upon the purpose of the analysis.

4.9.6 Soil Enrichment Analysis

The ATDM has been used to quantify the variability of plot-to-plot exposure by the plumes from the stacks of facilities in and

TABLE 40

COMPARISON OF TRACE ELEMENT CONCENTRATIONS (μg/g) IN TWO SOIL SAMPLING DEPTHS AT TWENTY PLOTS

	1.3-CM DEPTH		10-CM DEPTH	
	Extractable	Total	Extractable	Total
Element	mean/std-dev 1/	mean/std-dev	mean/std-dev	mean/std-dev
Cadmium (Cd)	0.13/0.03	0.5/0.0	0.08/0.03	0.5/0.0
Chromium (Cr)	0.07/0.02	49.5/10.1	0.04/0.02	48.9/13.6
Copper (Cu)	0.81/0.19	20.1/5.8	0.79/0.30	19.3/6.6
Lead (Pb)	1.67/0.66	24.9/4.2	0.82/0.23	12.1/5.6
Molybdenum (Mo)	2/	2/	0.06/0.02	1.5/0.0
Nickel (Ni)	0.99/0.32	24.4/7.6	0.95/0.43	24.0/8.9
Selenium (Se)	2/	2/	0.008/0.003	0.52/0.14
Sulfur (S)	2/	2/	1.3/1.3	312/106
Zinc (Zn)	3.29/1.74	83/11	2.2/2.1	75/12
Aluminum (Al)		52,450/6,230		52,920/7,340
Calcium (Ca)		9,550/2,680		15,650/15,060
Iron (Fe)		22,610/2,930		21,910/3,310
Potassium (K)		16,880/2,050		16,640/1,620
Magnesium (Mg)		6,560/1,670		7,820/4,120
Manganese (Mn)		505.7/69.3		474.3/130.8
Sodium (Na)		10,280/1,070		10,400/1,790
Titanium (Ti)		3,040/300		2,900/290

1/ Mean = arithmetic mean, std-dev = standard deviation.

2/ These elements are relatively mobile in the surface soil: due to project constraints, concentrations were not analyzed.

TABLE 41

RATIOS OF TRACE ELEMENT CONCENTRATIONS FROM TWO SOIL SAMPLING DEPTHS

	Extractable		Total	
Element	Mean Ratio[1]	$Z/P>\lvert Z\rvert$[2]	Mean Ratio[1]	$Z/P>\lvert Z\rvert$[2]
Cadmium	1.70	4.36/<0.01	1.00	0.00/1.00
Chromium	2.47	4.50/<0.01	1.05	0.49/0.63
Copper	1.08	0.87/<0.01	1.06	0.89/0.37
Lead	2.11	4.84/<0.01	2.65	5.13/<0.01
Nickel	1.40	0.38/0.71	1.07	0.12/0.90
Zinc	2.56	2.38/0.02	1.16	3.08/<0.01
Aluminum			1.00	-0.53/0.59
Calcium			0.94	0.19/0.85
Iron			1.05	0.47/0.64
Potassium			1.02	0.54/0.59
Magnesium			0.94	-0.22/0.83
Manganese			1.11	2.04/0.04
Sodium			1.01	-0.53/0.60
Titanium			1.05	1.22/0.22

---

[1] Ratio = concentration from 1.3-centimeter sample divided by concentration from 10-centimeter sample.

[2] Z = Mann-Whitney test statistic, $P>|Z|$ = probability of greater absolute value of z.

TABLE 42

CORRELATION BETWEEN TOTAL AND EXTRACTABLE SOIL CONCENTRATIONS

	Correlation Coefficient(R)/Probability of >|R|	
Element	1.3-cm Samples(20)	10-cm Samples(64)
Chromium	0.15/0.54	0.42/<0.01
Copper	0.75/<0.01	0.75/<0.01
Nickel	0.25/0.29	0.08/0.54
Lead	0.36/0.12	0.60/<0.01
Selenium		0.39/<0.01
Sulfur		-0.32/0.01
Zinc	0.03/0.90	0.32/0.01

surrounding the study area, Section 4.3. The deposition exposure factors for the plots have been correlated with the total element concentrations of the 1.3-cm and 10-cm soil samples. The correlation coefficients are listed in Table 43.

The correlation between the ATDM deposition exposure factor (DEP) and the total element concentration is greater for the 1.3-cm soil samples than for the 10-cm soil samples. The data in Table 43 imply that deposition was occurring during the 10 years of operation of the study facility prior to field sampling.

The soil plots were divided into two subgroups: those plot locations for which the deposition exposure factors (DEP) was equal to or less than 0.1 and those for which DEP was greater than 0.1, Figure 30. Mean elemental concentrations in the soil samples from the two subgroups were determined, Table 44. Larger concentrations for the subgroup of plots at locations with DEP greater than 0.1 would suggest soil enrichment by accumulation of atmospheric deposition from the study facility plume; assuming that the computer model (ATDM) represents the atmospheric deposition pattern.

The mean concentrations of elements for the soil subgroups do not consistently indicate the occurrence of soil enrichment. A statistical analysis of levels of significance of differences among subgroup means was not performed.

TABLE 43

CORRELATION BETWEEN MODEL DEPOSITION EXPOSURE FACTORS AND SOIL TOTAL ELEMENT CONCENTRATIONS

Correlation Coefficient(R)/Probability of >|R|

Element	1.3-cm Samples(20)	10-cm Samples(64)
Chromium	0.47/0.04	0.27/0.03
Copper	0.75/<0.01	0.40/<0.01
Nickel	0.61/<0.01	0.20/0.11
Lead	0.31/0.19	-0.10/0.43
Selenium		-0.05/0.69
Sulfur		0.13/0.30
Zinc	0.55/0.01	0.08/0.55
Aluminum	0.58/0.01	0.10/0.42
Calcium	0.17/0.48	0.27/0.03
Iron	0.41/0.07	0.03/0.83
Potassium	0.48/0.03	0.05/0.68
Magnesium	0.59/0.01	0.31/0.01
Manganese	0.43/0.06	-0.01/0.95
Sodium	-0.47/0.03	-0.23/0.07
Titanium	0.31/0.18	-0.06/0.67

TABLE 44

SOIL ELEMENT CONCENTRATIONS (μg/g) BY ATDM DEPOSITION FACTOR

	1.3-cm Samples		10-cm Samples	
Parameter	DEP≤0.1	DEP>0.1	DEP≤0.1	DEP>0.1
Number of Samples	6	14	29	35
pH			7.34	7.55
Cadmium				
E	0.127	0.129	0.097	0.080
T	0.500	0.500	0.500	0.500
Chromium				
E	0.067	0.076	0.030	0.033
T	48.50	49.86	50.27	47.97
Copper				
E	0.737	0.834	0.0730	0.0753
T	18.50	20.71	18.79	18.83
Molybdenum				
E			0.089	0.069
T			1.50	1.50
Nickel				
E	0.822	1.054	1.034	1.045
T	23.67	24.64	26.83	24.94
Lead				
E	2.082	1.494	0.964	0.826
T	25.50	24.57	16.21	13.34
Selenium				
E			0.007	0.007
T			0.59	0.53
Sulfur				
E			1.00	1.17
T			339	326
Zinc				
E	3.565	3.174	1.828	2.3
T	83.67	83.00	77.66	73.91
Aluminum				
T	52,000	52,614	54,129	53,460
Calcium				
T	9,183	9,707	9,314	14,203
Iron				
T	23,516	22,221	23,455	22,403
Potassium				
T	16,283	17,136	16,859	16,503
Magnesium				
T	6,417	6,621	6,100	7,391
Manganese				
T	531	495	489	457
Sodium				
T	10,500	10,179	10,469	10,614
Titanium				
T	3,167	2,979	3,041	2,891

Mean ratios of element concentrations in the 1.3-cm and 10-cm soil samples were presented in Table 41. Most of the 1.3-cm samples were taken from plots located northwest and southeast of the study facility on two transects, see Figure 13. The patterns of ratios for those plots located along the two transects are given in Figure 51. Ratios for those elements which were not statistically different (Table 41) are not shown.

The pattern of ratios, Figure 51, suggests a correlation between the various elements. That is, enrichment ratios of the surface layer of soil appear to become larger or smaller simultaneously among the elements from plot to plot.

A linear regression analysis was applied to soil samples from plots located on the three transects: NNW-SSE, NW-SE, and WNW-ESE, see Figure 13. Plots on these transects were stratified into two groups: the northwest and southeast directions.

The form of the regression equation was $\mathrm{Log}(S_x) = a_0 + b_1 \mathrm{Log}(DIS)$ where $\mathrm{Log}(S_x)$ is logrithm of extractable or total element (x) concentration in the soil sample, Log(DIS) is the logrithm of the distance from source to sampling plot, and a_0 and b_1 are the intercept and slope of the regression line (29). A negative coefficient suggests lower element concentrations at greater distances.

The results of the linear regression analysis are presented in Table 45. The predictor variable Log(DIS) does not explain

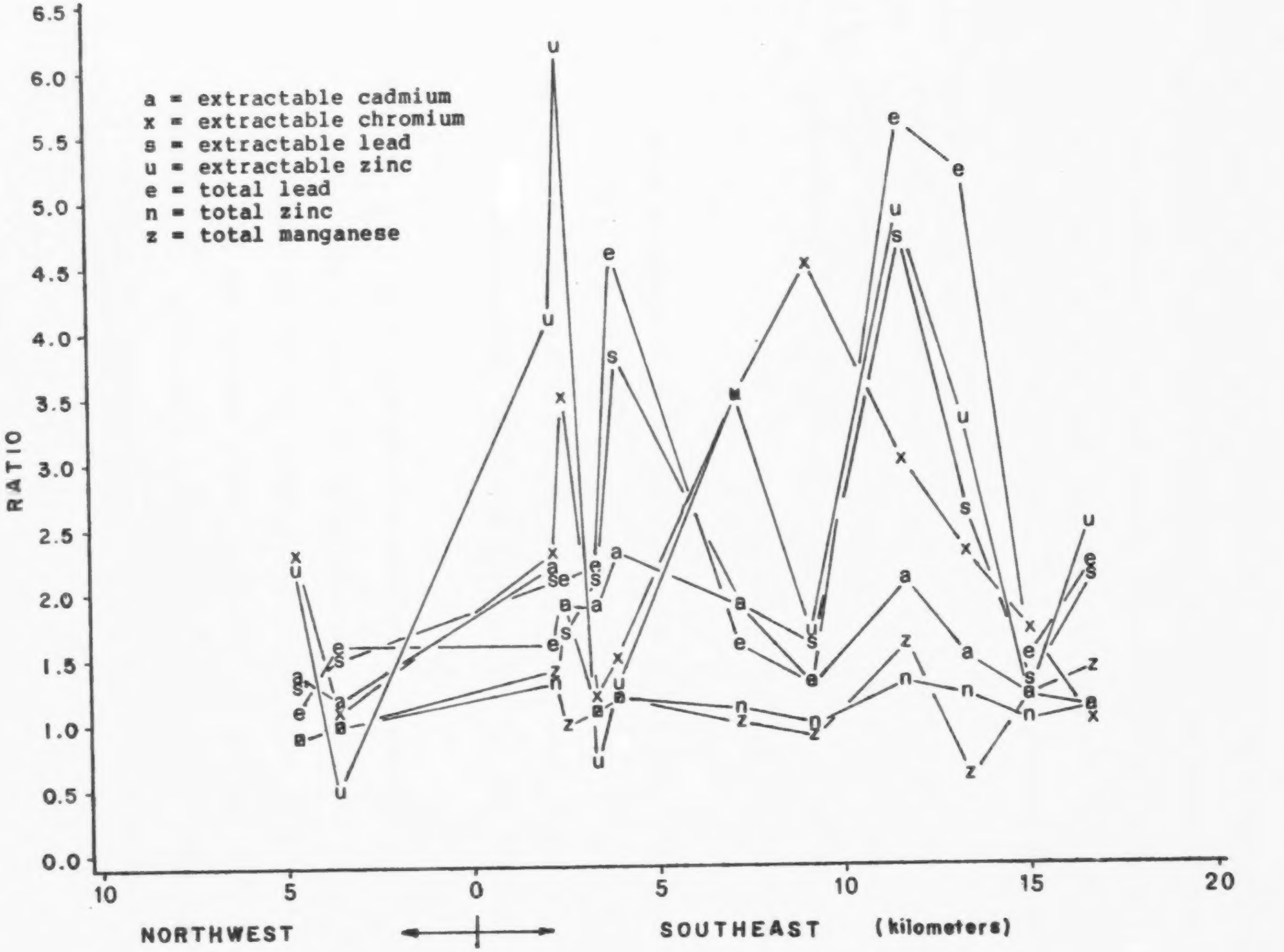

Figure 51. Ratios of element concentrations from 1.3-cm and 10-cm soil samples at plots located along two transects northwest and southwest of the study facility.

TABLE 45

LINEAR REGRESSION ANALYSIS OF SOIL ELEMENT DATA DEPENDENCE ON DISTANCE

	Northwest Direction				Southeast Direction							
	10-cm Samples (15)				10-cm Samples (22)				1.3-cm Samples (11)			
Element	a_0	b_1	R^2	$P>\lvert T\rvert$ 1/	a_0	b_1	R^2	$P>\lvert T\rvert$	a_0	b_1	R^2	$P>\lvert T\rvert$
Cadmium												
E	-1.06	+0.002	<0.001	1.00	-1.26	+0.15	0.042	0.36	-0.78	-0.13	0.147	0.25
T												
Chromium												
E	-0.84	-0.92	0.337	0.02	-1.53	+0.01	<0.001	0.97	-1.12	-0.07	0.049	0.51
T	+1.60	+0.12	0.153	0.15	+1.59	+0.07	0.039	0.38	+1.68	-0.01	0.001	0.92
Copper												
E	-0.10	-0.03	<0.001	0.93	-0.14	-0.08	-0.010	0.65	-0.09	-0.03	0.016	0.71
T	+1.23	+0.06	0.006	0.78	+1.21	-0.01	<0.001	0.93	+1.22	0.03	0.042	0.54
Molybdenum												
E	-1.48	+0.46	0.078	0.31	-1.53	+0.28	0.096	0.16				
T												
Nickel												
E	-0.08	+0.08	0.008	0.75	-0.13	+0.03	<0.001	0.90	+0.07	-0.14	0.104	0.33
T	+1.18	+0.31	0.123	0.20	+1.39	-0.04	0.007	0.71	+1.29	+0.06	0.087	0.38
Lead												
E	-0.11	+0.09	0.008	0.75	-0.26	+0.18	0.171	0.06	+0.04	+0.22	0.167	0.21
T	+0.87	+0.40	0.067	0.35	+0.91	+0.14	0.018	0.56	+1.37	+0.04	0.137	0.26
Selenium												
E	-1.55	-0.74	0.288	0.04	-2.16	-0.06	0.003	0.82				
T	-0.40	+0.18	0.102	0.25	-0.34	+0.02	0.001	0.90				
Sulfur												
E					+0.10	-0.08	0.010	0.65				
T	+2.40	+0.17	0.057	0.39	+2.56	-0.15	0.042	0.36				
Zinc												
E	+0.43	-0.28	0.022	0.60	+0.08	-0.03	<0.001	0.94	+0.71	-0.26	0.073	0.42
T	+0.77	+1.15	0.120	0.21	+1.74	+0.12	0.120	0.11	+1.90	+0.02	0.030	0.61
Aluminum												
T	+4.67	+0.09	0.096	0.26	+4.65	-0.07	0.084	0.21	+4.69	+0.03	0.102	0.37
Calcium												
T	+3.76	+0.19	0.040	0.47	+4.48	-0.50	0.138	0.09	+3.88	+0.08	0.189	0.18
Iron												
T	+4.31	+0.08	0.055	0.40	+4.20	+0.13	0.173	0.05	+4.26	+0.10	0.572	0.01
Potassium												
T	+4.25	-0.02	0.002	0.86	+4.31	+0.10	0.371	<0.01	+4.23	-0.02	0.009	0.78
Magnesium												
T	+3.75	+0.06	0.016	0.66	+4.03	-0.25	0.104	0.14	+3.73	+0.07	0.102	0.34
Manganese												
T	+2.74	-0.07	0.014	0.68	+2.53	+0.11	0.030	0.44	+2.64	+0.07	0.288	0.09
Sodium												
T	+4.11	-0.08	0.030	0.54	+3.90	+0.14	0.207	0.03	+4.01	+0.20	0.047	0.52
Titanium												
T	+3.46	+0.04	0.018	0.64	+3.36	+0.11	0.287	0.01	+3.44	+0.06	0.211	0.16

1/ a_0 is intercept (at 1 kilometer), b_1 is slope (coefficient of Log(DIS)), R^2 is the square of the multiple correlation coefficient and is the amount of variance of the element explained by the predictor Log(DIS), $P>|T|$ is probability of b_1 equal to zero.

the variance of element concentrations, with one exception which is total iron concentrations from 1.3-cm soil samples in the southeast direction. However, in this case only 57% of the variance of total iron concentrations is explained by the predictor. This analysis provided no evidence that soil enrichment has occurred in the study area during the 10 years of operation of Unit I.

4.10 Vegetation Data

4.10.1 Element Concentrations

Certain vegetation species may be indicators of potential enrichment of elements in vegetation by redistribution from the plumes of coal-fired power plants. Seven species of native vegetation occurring in the study area were sampled.

The mean concentrations of elements in the seven vegetation species are listed in Table 46. The concentrations of cadmium and lead, for all species, were often less than the minimum detectable levels of the analytical technique.

4.10.2 Seasonal Variations

Variations of element concentrations in vegetation during the growth cycle can be important in utilizing vegetation as indicators of element redistribution. Therefore, a second collection

TABLE 46

TRACE ELEMENT CONCENTRATIONS FOR EACH VEGETATION SPECIES (µg/g dry weight)

	Agropyron smithii	Andropogon scoparius	Carex eleocharis	Koeleria cristata1/	Oxytropis lambertii	Stipa comata	Vicia americana
Number of Samples:	47	21	33	46	33	48	18
Element:	mean/std-dev2/	mean/std-dev	mean/std-dev	mean/std-dev	mean/std-dev	mean/std-dev	mean/std-dev
Aluminum (Al)	80/61	152/76	269/114	134/96	108/57	39/25	127/72
Calcium (Ca)	2,200/500	2,000/400	7,000/1,100	2,200/300	7,300/2,100	1,400/300	13,100/3,100
Cadmium (Cd)	0.07/0.11	0.07/0.03	0.08/0.05	0.06/0.02	0.06/0.03	0.05/0.01	0.06/0.02
Chromium (Cr)	3.9/2.5	20.3/10.4	3.0/1.2	2.6/2.0	0.9/0.2	2.5/1.7	1.3/0.5
Copper (Cu)	2.8/0.4	2.5/0.5	2.5/0.4	3.1/0.8	4.1/1.0	3.0/0.5	6.8/1.6
Iron (Fe)	93/54	198/91	230/85	134/77	105/39	54/24	133/58
Potassium (K)	14,500/2,000	8,900/1,100	19,500/2,100	12,600/2,100	20,800/2,400	13,300/2,400	20,400/2,000
Lead (Pb)	1.5/0.0	1.5/0.0	1.5/0.0	1.5/0.0	1.5/0.0	1.5/0.0	1.5/0.0
Magnesium (Mg)	1,000/200	1,000/100	1,700/300	1,100/100	3,100/500	1,400/2,100	2,900/400
Manganese (Mn)	33/12	29/7	45/12	62/16	17/9	16/4	56/19
Molybdenum (Mo)	1.0/0.5	1.7/0.9	0.7/0.2	1.1/1.0	1.1/0.6	0.5/0.3	1.0/0.6
Sodium (Na)	46/29	55/11	73/13	44/20	99/21	55/24	184/244
Nickel (Ni)	2.6/1.6	12.3/6.4	2.1/0.8	3.6/1.4	2.5/0.4	2.8/1.0	2.9/0.6
Phosphorus (P	1,400/300	600/100	1,400/1,700	1,600/300	2,000/300	1,200/200	2,300/300
Selenium (Se)	0.24/0.15	0.10/0.05	0.24/0.20	0.15/0.10	0.23/0.13	0.12/0.11	0.40/0.29
Sulfur (S)	1110/310	50/10	1000/170	1020/400	1480/300	730/320	2220/520
Zinc (Zn)	15.8/2.9	12.9/3.0	13.4/4.9	19.9/3.1	11.0/2.5	12.2/1.6	31.3/7.9

1/ June collection.
2/ Mean is arithmetic mean, std-dev is standard deviation of concentrations.

of Koeleria cristata (June Grass) was obtained from 17 of the 46 plots on which it occurred.

The mean concentrations of elements in the September collection and June collection of June Grass from the 17 plots are given in Table 47. Mean ratios of the September collection versus the June collection are given in Table 48. The standard deviation and coefficient of variation for each element are also shown in Table 48. The plot-to-plot variability of ratios was lower for calcium and magnesium than for other elements.

The Mann-Whitney rank test was applied to the ranked distributions of concentrations of each element from the two collections. The test statistic, Z, and the probability of a greater Z are also given in Table 48. The results of the Mann-Whitney rank test indicate that the concentrations of elements between the two collections are significantly different for all elements except cadmium, calcium, and lead.

The correlation between element concentrations are shown for each collection of Koleria cristata in Table 49. Correlation among concentrations for aluminum, chromium, copper, iron, molybdenum, and nickel suggest that these elements reach consistent proportions from specimen-to-specimen when the species ages. In contrast, manganese, sulfur, and zinc become less correlated with aluminum, chromium, copper, iron, and nickel.

TABLE 47

COMPARISON OF TRACE ELEMENT CONCENTRATIONS (μg/g dry weight) IN KOELERIA CRISTATA AT TWO STAGES OF GROWTH FROM SEVENTEEN PLOTS

	Anthesis[1]	Mature[2]
Element	mean/std-dev[3]	mean/std-dev
Aluminum	120/103	371/207
Calcium	2,100/280	2,300/290
Cadmium	0.06/0.02[4]	0.06/0.02[4]
Chromium	2.4/1.5	29.4/17.1
Copper	3.2/0.7	1.7/0.3
Iron	124/84	413/220
Potassium	13,100/1,600	2,300/400
Magnesium	1,040/150	660/80
Manganese	67/18	49/11
Molybdenum	1.3/1.5	2.3/1.3
Sodium	45/18	76/8
Nickel	3.5/0.9	17.4/10.3
Phosphorus	1,700/300	400/100
Lead	1.5/0.0[4]	1.8/0.8[4]
Sulfur	1050/590	130/60
Selenium	0.15/0.09	0.09/0.03
Zinc	20.1/3.8	10.6/4.2

---

[1] June collection.

[2] September collection.

[3] mean is arithmetic mean, std-dev is standard deviation.

[4] The concentrations of these elements were generally less than minimum detectable levels of the laboratory analytical techniques.

TABLE 48

RATIOS OF ELEMENT CONCENTRATIONS FROM TWO COLLECTIONS OF KOELERIA CRISTATA

	Ratios[1]		
Element	Mean	std-dev/CV[2]	$Z/P>\lvert Z\rvert$[3]
Aluminum	3.43	0.93/27	-4.10/<0.01
Calcium	1.06	0.11/10	-1.04/0.30
Cadmium	1.13	0.34/30	-0.54/0.59
Chromium	12.76	4.75/37	-4.86/<0.01
Copper	0.56	0.19/33	4.79/<0.01
Iron	3.41	0.82/24	-4.43/<0.01
Potassium	0.18	0.03/15	4.90/<0.01
Magnesium	0.64	0.09/14	4.86/<0.01
Manganese	0.76	0.21/28	3.30/<0.01
Molybdenum	2.64	1.62/61	-3.75/<0.01
Sodium	2.00	1.09/54	-4.29/<0.01
Nickel	4.64	2.03/44	-4.75/<0.01
Phosphorus	0.22	0.06/25	4.90/<0.01
Lead	1.21	0.57/47	-0.58/0.56
Sulfur	0.16	0.12/73	4.81/<0.01
Selenium	0.77	0.52/68	2.52/0.01
Zinc	0.53	0.17/32	4.36/<0.01

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[1] Ratio is concentration of September collection divided by concentration of June collection.

[2] std-dev = standard deviation of ratios, CV = coefficient of variation.

[3] Z = Mann-Whitney rank test statistic, $P>\lvert Z\rvert$ = probability (P) of greater absolute value of Z.

TABLE 49

CORRELATION COEFFICIENTS MATRIX FOR ELEMENT CONCENTRATIONS FROM TWO COLLECTIONS OF KOELERIA CRISTATA

June Collection

September Collection

	Al	Ca	Cr	Cu	Fe	K	Mg	Mn	Mo	Ni	Na	P	Se	S	Zn
Aluminum (Al)		0.37	0.95	−0.14	0.99	−0.39	0.38	0.43	−0.07	−0.80	0.01	0.51	0.13	0.63	0.72
Calcium (Ca)	0.40		0.32	0.23	0.40	−0.08	0.69	0.41	0.30	0.64	0.37	0.60	0.34	0.54	0.59
Chromium (Cr)	0.91	0.39		−0.19	0.95	−0.54	0.26	0.32	−0.09	0.76	−0.04	0.45	0.14	0.62	0.58
Copper (Cu)	0.85	0.48	0.85		−0.17	0.36	0.06	0.44	0.50	0.14	−0.13	0.32	0.06	−0.23	0.23
Iron (Fe)	0.98	0.45	0.95	0.88		−0.41	0.38	0.42	−0.07	0.78	0.05	0.50	0.15	0.68	0.70
Potassium (K)	0.01	−0.32	−0.14	−0.50	−0.07		0.34	0.40	0.33	−0.21	−0.06	0.16	−0.14	−0.39	−0.06
Magnesium (Mg)	0.28	−0.09	0.31	0.32	0.25	−0.02		0.50	0.30	0.51	0.57	0.74	0.13	0.30	0.60
Manganese (Mn)	−0.09	−0.05	0.01	−0.19	0.08	0.04	0.25		0.66	0.44	0.04	0.71	−0.03	0.01	0.63
Molybdenum (Mo)	0.78	0.39	0.94	0.76	0.89	−0.03	0.32	0.03		0.09	0.19	0.61	0.06	−0.01	0.11
Nickel (Ni)	0.89	0.39	0.99	0.84	0.96	−0.13	0.32	0.02	0.96		0.05	0.56	0.41	0.45	0.66
Sodium (Na)	0.54	−0.01	0.65	0.40	0.54	0.10	0.21	−0.16	0.65	0.64		0.25	−0.09	0.20	0.22
Phosphorus (P)	0.58	0.03	0.59	0.30	0.56	0.28	0.37	0.48	0.60	0.61	0.37		0.25	0.2	0.63
Selenium (Se)	0.27	0.03	0.34	0.28	0.33	−0.12	0.21	−0.32	0.20	0.30	0.35	−0.16		−0.18	0.17
Sulfur (S)	−0.12	−0.08	−0.15	0.02	−0.17	0.03	0.24	−0.28	−0.28	−0.17	−0.15	−0.31	0.44		0.55
Zinc (Zn)	−0.10	−0.12	−0.01	−0.06	−0.06	−0.16	0.20	0.06	−0.02	−0.02	0.09	−0.14	0.69	0.11	

4.10.3 Vegetation-Soil Relationships

The uptake of an element by vegetation from soil can be represented by the ratio of the vegetation concentration divided by the soil concentration. These ratios were computed for each plot and the mean ratio calculated for all plots. The extractable concentrations from the 10-cm soil samples were used in the calculations. The vegetation-soil ratios of element concentrations are presented in Table 50.

The vegetation-soil ratios of element concentrations vary among the vegetation species. Ratios for cadmium, copper, lead, and zinc are more uniform among species than the other elements shown in Table 50.

Since the accumulation of elements in vegetation varies during the growing season, the vegetation-soil ratios will also vary. The vegetation-soil ratios for the two collections of *Koeleria cristata* reflect the seasonal change of concentrations in this species.

The large standard deviations for most of the vegetation-soil ratios suggest poor correlation between element concentrations in vegetation and extractable soil concentrations. Table 51 lists the correlation coefficient of vegetation element concentrations and extractable soil concentrations. Clearly, concentrations of some elements in vegetation depend on factors other than extractable soil concentrations: assuming that

TABLE 50

VEGETATION-SOIL RATIOS OF ELEMENT CONCENTRATIONS

	Agropyron smithii	Andropogon scoparius	Carex eleocharis	Koeleria cristata	Koeleria cristata	Oxytropis lambertii	Stipa comata	Vicia americana
Growth Stage Element	mature mean/std-dev3/	mature mean/std-dev	mature mean/std-dev	anthesis1/ mean/std-dev	mature2/ mean/std-dev	full bloom mean/std-dev	mature mean/std-dev	full bloom mean/std-dev
Cadmium (Cd)	0.88/1.11	1.06/0.65	1.17/1.04	0.73/0.33	0.91/0.35	0.87/0.60	0.71/0.46	0.73/0.29
Chromium (Cr)	150.8/119.0	895.2/745.5	109.3/49.3	99.9/90.5	1059/678	35.2/13.2	92.1/67.7	38.4/18.7
Copper (Cu)	4.8/3.2	4.5/2.2	4.1/1.7	4.8/2.7	3.4/3.1	7.3/3.6	4.6/2.2	9.4/3.0
Molybdenum (Mo)	19.3/16.4	31.3/19.2	14.6/8.8	18.3/24.3	40.3/15.9	17.3/11.3	8.5/6.5	18.0/12.3
Nickel (Ni)	3.4/3.6	16.8/12.3	2.7/1.7	4.2/2.6	26.7/19.9	3.0/1.5	3.3/2.2	3.0/0.8
Lead (Pb)	1.9/0.6	2.0/0.6	2.0/0.6	1.9/0.5	2.5/0.9	1.9/0.6	1.9/0.5	1.9/0.6
Selenium (Se)	44.5/45.1	17.6/14.2	37.6/32.4	23.3/19.2	13.6/4.0	37.8/26.6	18.9/15.9	54.2/36.7
Sulfur (S)	1090/340	50/10	970/230	1010/420	120/70	1480/300	720/330	2220/520
Zinc (Zn)	15.9/15.6	15.6/12.6	14.5/12.7	17.5/15.9	11.4/10.0	11.5/9.3	11.2/11.0	21.4/17.2

1/ June collection.
2/ September collection.
3/ Mean is arithmetic mean ratio, std-dev is standard deviation of ratios for all plots.

TABLE 51

CORRELATION COEFFICIENTS BETWEEN ELEMENT CONCENTRATIONS IN VEGETATION AND SOIL

Correlation Coefficient (R)/Probability of Greater Absolute R

Element	Agropyron smithii	Andropogon scoparius	Carex eleocharis	Koeleria cristata[1]	Koeleria cristata[2]	Oxytropis lambertii	Stipa comata	Vicia americana
Cadmium	0.07/0.65	0.18/0.43	-0.07/0.72	0.10/0.51	0.40/0.11	-0.16/0.36	-0.30/0.04	0.08/0.77
Chromium	-0.05/0.72	-0.21/0.35	0.51/ 0.01	-0.11/0.46	-0.03/0.91	0.06/0.73	0.07/0.62	0.31/0.21
Copper	-0.07/0.63	0.17/0.45	0.34/0.06	0.001/0.996	-0.15/0.56	0.25/0.16	0.14/0.32	0.34/0.17
Molybdenum	-0.21/0.16	0.46/0.04	-0.06/0.75	-0.008/0.96	0.70/ 0.01	0.33/0.06	-0.12/0.41	-0.13/0.60
Nickel	-0.11/0.43	0.27/0.24	0.37/0.04	0.11/0.46	-0.05/0.86	0.44/0.01	-0.14/0.33	0.57/0.01
Lead	0.	0.	0.	0.	0.42/0.09	0.	0.	0.
Selenium	-0.01/0.94	0.33/0.15	0.29/0.10	0.11/0.47	0.33/0.19	0.22/0.21	0.31/0.03	0.17/0.51
Sulfur	0.09/0.56	0.	0.003/0.97	-0.08/0.58	-0.11/0.67	0.	0.08/0.60	0.
Zinc	-0.08/0.61	-0.03/0.89	0.52/ 0.01	0.37/0.01	0.84/ 0.01	0.28/0.11	0.06/0.66	0.30/0.23

[1] June collection.
[2] September collection.

the extractable soil concentration properly represents the portion of the total soil concentration which is available to plants.

4.10.4 Vegetation Enrichment Analysis

The vegetation and soil ecosystem surrounding a coal-fired electrical generating facility may respond in many ways from the redistribution of elements contained in plumes of the facility. Among factors affecting the response are climate and weather variability, species-to-species biological differences, and soil type differences.

In Section 4.3, Figure 29, it was demonstrated that the exposure of vegetation to the plumes of the facilities in and surrounding the study area is highly variable by direction and distance from the facility.

The vegetation plots were divided into two subgroups: these plot locations for which the air concentration exposure factors (CON) was equal to or less than 0.4 and those for which CON was greater than 0.4. Mean concentrations of elements for each of the subgroups of vegetation were determined, Table 52. Larger concentrations of elements for the subgroups of plots at locations with CON greater than 0.4 would suggest enrichment of elements in vegetation; assuming that the computer model represents the plume ground-level air concentration of elements.

TABLE 52

VEGETATION ELEMENT CONCENTRATIONS (μg/g) STRATIFIED BY ATDM AIR CONCENTRATION EXPOSURE FACTOR
(CON $0 \le 0.4$ / CON > 0.4)

	Agropyron smithii	Andropogon scoparius	Carex eleocharis	Koeleria cristata[1]	Koeleria cristata[2]	Oxytropis lambertii	Stipa comata	Vicia americana
Number of Samples:	10/37	2/19	5/28	9/37	5/12	5/28	9/39	7/11
Aluminum	80/80	163/151	264/271	162/127	425/348	123/106	58/35	153/110
Cadmium	0.05/0.08	0.05/0.08	0.05/0.08	0.06/0.06	0.07/0.06	0.06/0.06	0.06/0.05	0.06/0.06
Calcium	2,400/2,200	2,100/2,000	7,400/7,000	2,200/2,200	2,400/2,200	7,000/7,300	1,600/1,300	12,500/13,600
Chromium	4.1/3.9	18.0/20.6	3.0/3.0	2.8/2.6	35.4/26.9	0.9/0.9	3.2/2.4	1.4/1.2
Copper	2.9/2.7	2.1/2.6	2.1/2.5	3.1/3.1	1.8/1.7	3.5/4.2	3.0/2.9	6.0/7.3
Iron	93/93	202/198	230/230	156/128	474/387	118/103	70/49	156/117
Lead	1.5/1.5	1.5/1.5	1.5/1.5	1.5/1.5	1.5/1.9	1.5/1.5	1.5/1.5	1.5/1.5
Magnesium	950/1,050	850/1,060	1,640/1,710	1,030/1,060	660/660	3,200/3,090	780/1,560	2,890/2,900
Manganese	35/32	39/28	45/45	67/61	57/46	16/17	18/16	56/56
Molybdenum	1.1/1.0	1.1/1.7	0.6/0.8	1.5/1.0	2.5/2.1	1.2/1.0	0.6/0.5	0.9/1.0
Nickel	2.6/2.6	10.8/12.4	2.0/2.1	3.4/3.7	21.0/15.9	2.7/2.5	3.0/2.8	2.9/2.9
Phosphorus	1,400/1,400	700/600	900/1,500	1,700/1,600	400/340	2,200/2,000	1,200/1,200	2,300/2,300
Potassium	13,400/14,800	9,100/8,900	20,100/19,400	12,000/12,800	2,100/2,400	21,300/20,800	13,100/13,300	21,300/19,800
Selenium	0.22/0.25	0.06/0.10	0.15/0.25	0.12/0.16	0.08/0.09	0.23/0.23	0.10/0.13	0.46/0.36
Sodium	42/48	70/53	74/73	52/42	76/76	100/99	63/54	310/102
Sulfur	1,010/1,140	50/53	980/1000	1,410/930	110/130	1,440/1,490	780/720	2,300/2,170
Zinc	17.1/15.4	10.6/13.1	11.3/13.8	21.5/19.5	9.4/11.1	10.7/11.0	12.6/12.1	31.7/31.4

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[1] June collection.

[2] September collection.

The mean concentrations of elements for the vegetation subgroups do not provide any evidence of element enrichment in vegetation. A statistical analysis of levels of signficance of difference among subgroup means was not performed.

Certain statistical techniques, such as analysis of variance, for evaluating the presence of direction and distance relationships in vegetation and soil data require a uniform grid spacing. The logistics of field sampling precluded a uniform grid network in this project. Therefore, an alternate method of evaluating the data becomes necessary.

A statistical method which utilizes all of the available information from sampling plots in all directions and at non-uniform distances is desirable. Further, species uptake of elements from soil, intake from deposition onto leaves, and intake from gaseous absorption by leaves was expected to vary among the species sampled, the elements analyzed, and the exposure to the redistribution process.

Some analyses of vegetation trace element concentrations have used the linear regression model of $\text{Log}(V_x) = a_0 + b_1 \text{Log(DIS)}$: $\text{Log}(V_x)$ is logrithm (base 10) of the element (x) concentration in a vegetation species, Log(DIS) is the logrithm (base 10) of the distance from potential source to the vegetation plot receptor, and a_0 and b_1 are the intercept and slope, respectively, of the regression line (30). This linear model was applied to trace element concentrations for each vegetation species collected from plots located on the three transects northwest and southeast of the study facility. The results of the analysis are presented in Table 53.

Regressions having an R^2 (square of the multiple correlation coefficient) value greater than 0.300 are suggestive of a response to selected elements by certain vegetation species. For example, copper concentrations in Carex eleocharis become smaller at greater distances in the northwest direction. However, this analysis does not consider the possible combinations of exposures by vegetation to ground-level air concentrations in plumes and atmospheric deposition (see Figures 29 and 30 and refer to Section 4.3). Statistically insignificant regression line slopes may not indicate a lack of vegetation response.

A multiple linear regression analysis was applied to the vegetation, soil and ATDM data. Two forms of the regression model were used as shown below:

$$V_x = a_0 + f\,[b_1\,ph + b_2\,E_x + b_3\,CON + b_4\,DEP]$$

and,

$$Log\,(V_x) = a_0 + f\,[b_1\,ph + b_2\,Log(E_x) + b_3\,CON + b_4\,DEP]$$

TABLE 53

LINEAR REGRESSION ANALYSIS OF VEGETATION DATA DEPENDENCE ON DISTANCE

	Northwest Direction					Southeast Direction				
	N	a_0	b_1	R^2	P>|T|1/	N	a_0	b_1	R^2	P>|T|
Chromium										
Agropyron smithii	10	0.70	-0.065	0.001	0.93	20	0.65	-0.197	0.073	0.25
Andropogon scoparius	8	1.39	-0.001	< 0.001	0.97	13	1.19	-0.0003	< 0.001	0.97
Carex eleocharis	9	0.55	-0.013	0.017	0.74	16	0.53	-0.008	0.058	0.37
Koeleria cristata (1)	11	0.34	+0.012	0.052	0.50	17	0.24	-0.	< 0.001	1.00
Koeleria cristata (2)	4	1.47	+0.013	0.007	0.92	10	1.36	-0.010	0.070	0.46
Oxytropis lambertii	9	-0.15	+0.022	0.330*	0.11	15	-0.04	-0.003	0.008	0.75
Stipa comata	12	0.45	-0.017	0.022	0.65	18	0.32	-0.003	0.002	0.85
Vicia americana	2	0.36	-0.043	1.000	0.	5	0.16	-0.016	0.681*	0.12
Copper										
Agropyron smithii		0.42	+0.035	0.007	0.81		0.54	-0.127	0.393*	< 0.01
Andropogon scoparius		0.49	-0.004	0.071	0.52		0.32	+0.005	0.086	0.33
Carex eleocharis		0.53	-0.024	0.553*	0.02		0.44	+0.007	0.215	0.21
Koeleria cristata (1)		0.51	-0.017	0.326*	0.07		0.44	+0.006	0.103	0.21
Koeleria cristata (2)		0.24	*0.004	0.037	0.81		0.20	-0.002	0.043	0.56
Oxytropis lambertii		0.69	-0.014	0.153	0.30		0.57	+0.010	0.093	0.27
Stipa comata		0.50	-0.009	0.137	0.24		0.49	+0.001	0.004	0.81
Vicia americana		0.88	-0.013	1.000	0.		0.73	+0.012	0.355*	0.29
Molybdenum										
Agropyron smithii		-0.08	+0.004	< 0.001	0.99		-0.17	+0.166	0.023	0.52
Andropogon scoparius		0.34	+0.002	0.001	0.95		0.04	+0.003	0.006	0.80
Carex eleocharis		0.03	-0.026	0.185	0.25		-0.20	+0.008	0.048	0.41
Koeleria cristata (1)		-0.15	-0.003	0.001	0.91		-0.12	+0.010	0.014	0.66
Koeleria cristata (2)		0.18	+0.034	0.033	0.82		0.15	+0.008	0.079	0.43
Oxytropis lambertii		-0.45	+0.066	0.485*	0.04		-0.26	+0.026	0.066	0.36
Stipa comata		-0.31	+0.004	0.005	0.82		-0.42	-0.002	0.002	0.86
Vicia americana		-0.002	-0.026	1.000	0.		-0.08	-0.010	0.175	0.48
Nickel										
Agropyron smithii		0.59	-0.110	0.004	0.87		0.47	-0.212	0.070	0.26
Andropogon scoparius		1.16	+0.0004	< 0.001	0.99		0.97	0.	< 0.001	0.99
Carex eleocharis		0.40	-0.018	0.035	0.63		0.38	-0.010	0.079	0.29
Koeleria cristata (1)		0.55	-0.004	0.011	0.76		0.52	-0.001	< 0.001	0.93
Koeleria cristata (2)		1.19	+0.020	0.014	0.88		1.12	-0.007	0.044	0.56
Oxytropis lambertii		0.31	+0.011	0.127	0.35		0.38	+0.002	0.003	0.84
Stipa comata		0.54	-0.015	0.038	0.54		0.36	+0.003	0.011	0.69
Vicia americana		0.68	-0.033	1.000	0.		0.56	-0.010	0.435*	0.23

TABLE 53 (Continued)

Selenium								
Agropyron smithii	-0.70	+0.181	0.012	0.76	-0.55	-0.273	0.061	0.29
Andropogon scoparius	-0.85	-0.008	0.070	0.53	-1.29	+0.018	0.154	0.18
Carex eleocharis	-0.14	-0.128	0.408*	0.06	-0.66	-0.017	0.042	0.45
Koeleria cristata (1)	-0.72	-0.022	0.071	0.43	-0.92	-0.001	0.001	0.92
Koeleria cristata (2)	-0.97	-0.005	0.004	0.93	-0.95	-0.016	0.378*	0.06
Oxytropis lambertii	-0.90	-0.014	0.056	0.54	-0.57	-0.016	0.038	0.49
Stipa comata	-0.75	-0.028	0.018	0.67	-1.16	+0.016	0.101	0.20
Vicia americana	0.32	-0.097	1.000	0.	-0.78	+0.015	0.153	0.52
Sulfur								
Agropyron smithii	2.73	+0.445	0.425*	0.04	3.03	-0.	<0.001	1.00
Andropogon scoparius	1.69	+0.009	0.070	0.53	1.69	+0.	<0.001	1.00
Carex eleocharis	3.15	-0.021	0.201	0.23	3.04	-0.008	0.460*	<0.01
Koeleria cristata (1)	3.01	-0.007	0.034	0.59	3.08	-0.022	0.250	0.04
Koeleria cristata (2)	2.04	+0.022	0.030	0.83	2.19	-0.014	0.200	0.20
Oxytropis lambertii	3.07	+0.018	0.208	0.22	3.26	-0.013	0.285	0.04
Stipa comata	2.48	+0.025	0.013	0.73	2.84	+0.008	0.114	0.17
Vicia americana	3.39	-0.004	1.000	0.	3.17	+0.010	0.387*	0.26
Zinc								
Agropyron smithii	1.15	+0.024	0.002	0.90	1.21	-0.002	0.005	0.78
Andropogon scoparius	1.16	+0.007	0.077	0.50	1.01	-0.004	0.068	0.39
Carex eleocharis	1.39	-0.045	0.564*	0.02	1.14	-0.012	0.076	0.30
Koeleria cristata (1)	1.33	-0.008	0.080	0.40	1.33	-0.006	0.159	0.11
Koeleria cristata (2)	0.81	+0.030	0.435*	0.34	1.15	-0.013	0.256	0.14
Oxytropis lambertii	1.00	-0.001	0.003	0.90	1.15	-0.012	0.120	0.21
Stipa comata	1.05	+0.003	0.057	0.46	1.10	-0.001	0.007	0.74
Vicia americana	1.45	+0.014	1.000	0.	1.38	0.006	0.045	0.73

1/ a_0 is intercept at DIS equal to one kilometer, b_1 is slope of regression, R^2 is square of multiple correlation coefficient and fraction of element concentration variance explained by DIS, $P>|T|$ is probability that b_1 is equal to zero.

V_x was the concentration of element x in the particular species, pH was the pH of 10-cm soil sample, E_x was the extractable concentration of element x in the 10-cm soil sample, and CON and DEP were the ground-level air concentration and total deposition exposure factors, respectively, (from Section 4.3, Figures 29 and 30). At a given sampling plot, the predictor variables remain the same for each vegetation species.

Positive coefficients for CON and DEP predictors are suggestive of an interaction by the vegetative species with the power plant plumes.

The results of the stepwise linear regression analysis are presented in Table 54. Cadmium and lead were not included in this analysis because concentrations in vegetation were generally less than detectable levels of laboratory analytical procedures. The form which produced the largest R^2 is given in the table.

The amount of variance of V_x explained by only pH and E_x predictors of V_x, is also shown in Table 54. These parameters are generally not good predictors of element concentrations in vegetation, since values of R^2 are less than 0.500 with two exceptions. Clearly, the plot-to-plot variability of concentrations of elements in vegetations depends upon additional factors.

The different results of the regression analysis for the two collections of Koeleria cristata are particularly noteworthy. The amount of variance of element concentration, which was

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TABLE 54

MULTIPLE LINEAR REGRESSION MODELS FOR VEGETATION TRACE ELEMENT CONCENTRATIONS

	Variance Explained by pH and E_x only	Variance Explained by Model	Model
Agropyron smithii			
chromium	0.116	0.122	Log(CR) = -0.40 + 0.12 pH + 0.15 DEP
copper	0.052	0.060	CU = +1.69 + 0.13 pH + 0.35 CON
molybdenum	0.147	0.147	Log(MO) = -1.32 + 0.19 pH + 0.03 Log(EMO)
nickel	0.091	0.091	Log(NI) = -0.59 + 0.13 pH + 0.11 Log(ENI)
selenium	0.032	0.040	Log(SE) = -1.62 + 0.07 pH - 0.16 Log(ESE) + 0.11 CON
sulfur	0.016	0.159	Log(S) = +2.71 + 0.03 pH + 0.10 Log(ES) + 0.17 CON - 0.18 DEP
zinc	0.049	0.099	Log(ZN) = +1.55 - 0.04 pH - 0.05 Log(EZN) - 0.05 CON - 0.09 DEP
Andropogon scoparius			
chromium	0.126	0.464	Log(CR) = +0.86 - 0.07 pH - 0.12 Log(ECR) + 0.87 CON + 1.26 DEP
copper	0.264	0.430	CU = +3.91 - 0.33 pH + 1.34 CON + 1.18 DEP
molybdenum	0.293	0.502	Log(MO) = -0.03 + 0.34 Log(EMO) + 0.71 CON + 0.81 DEP
nickel	0.051	0.441	Log(NI) = +0.72 - 0.06 pH + 0.89 CON + 1.26 DEP
selenium	0.123	0.596	Log(SE) = -0.69 + 0.06 pH + 0.32 Log(ESE) + 0.99 CON + 0.75 DEP
sulfur	0.028	0.167	S = +0.32 + 4.69 pH + 22.49 CON
zinc	0.047	0.357	Log(ZN) = +0.80 +0.37 CON + 0.22 DEP
Carex eleocharis			
chromium	0.315	0.341	CR = -2.93 + 0.43 pH + 57.3 ECR + 0.84 CON + 2.91 DEP
copper	0.124	0.275	CU = +1.96 + 0.12 pH + 0.56 ECU - 0.74 CON - 2.19 DEP
molybdenum	0.001	0.066	Log(MO) = -0.29 + 0.03 pH - 0.42 DEP
nickel	0.279	0.279	NI = -4.84 + 0.72 pH + 1.54 ENI
selenium	0.110	0.120	Log(SE) = +0.59 + 0.06 pH + 0.44 Log(ESE) + 0.39 DEP
sulfur	0.007	0.017	Log(S) = +2.94 + 0.005 pH + 0.083 DEP
zinc	0.271	0.310	ZN = +16.8 + 1.32 EZN - 6.47 CON - 11.03 DEP
Koeleria cristata (1)			
chromium	0.076	0.076	Log(CR) = +0.31 - 0.06 pH - 0.34 Log(ECR)
copper	0.020	0.207	Log(CU) = +0.64 + 0.08 Log(ECU) - 0.23 CON
molybdenum	0.122	0.168	Log(MO) = -0.02 + 0.13 pH + 0.64 Log(EMO) - 0.35 CON - 0.19 DEP
nickel	0.008	0.064	Log(NI) = +0.67 - 0.15 CON - 0.23 DEP
selenium	0.112	0.112	Log(SE) = +0.70 - 0.14 pH + 0.27 Log(ESE)
sulfur	0.059	0.128	Log(S) = +2.67 + 0.06 pH - 0.15 Log(ESU) - 0.22 CON
zinc	0.201	0.246	Log(ZN) = +1.33 + 0.07 Log(EZN) - 0.07 CON

TABLE 54 (Continued)

Koeleria cristata2/			
chromium	0.042	0.135	CR = +136.8 - 10.1 pH - 42.1 CON - 30.5 DEP
copper	0.051	0.295	CU = +3.94 + 0.16 pH - 1.25 CON - 1.54 DEP
molybdenum	0.506	0.643	Log(MO) = +1.16 + 0.12 pH + 1.00 Log(EMO) - 0.58 CON - 0.99 L.
nickel	0.003	0.115	Log(NI) = +1.75 + 0.21 Log (ENI) - 0.69 CON - 0.89 DEP
selenium	0.290	0.398	Log(SE) = +0.13 + 0.06 pH - 0.38 Log(ESE) + 0.45 DEP
sulfur	0.075	0.215	S = -308 + 35.9 pH + 198 CON + 265. DEP
zinc	0.706	0.714	ZN = +9.23 - 1.76 EZN + 3.03 DEP
Oxytropis lambertii			
chromium	0.052	0.142	Log(CR) = -0.01 + 0.14 (ECR) + 0.17 CON + 0.47 DEP
copper	0.138	0.251	Log(CU) = +0.47 + 0.18 + 0.21 CON + 0.19 DEP
molybdenum	0.204	0.224	Log(MO) = -0.40 + 0.15 pH + 0.68 Log(EMO) + 0.47 CON
nickel	0.251	0.381	Log(NI) = +0.25 + 0.04 pH + 0.24 Log (ENI) - 0.17 CON - 0.17 DEP
selenium	0.245	0.344	Log(SE) = +1.18 + 0.11 pH + 0.38 Log(ESE) - 0.35 CON
sulfur	0.001	0.114	Log(S) = +3.12 + 0.01 pH + 0.13 CON - 0.40 DEP
zinc	0.164	0.184	ZN = +1.07 + 1.10 pH + 0.64 EZN + 4.55 DEP
Stipa comata			
chromium	0.008	0.163	CR = +2.97 - 1.15 pH + 4.42 DEP
copper	0.107	0.180	Log(CU) = +0.38 + 0.02 pH + 0.11 Log (ECU) - 0.09 CON
molybdenum	0.133	0.194	MO = -0.53 + 0.13 pH + 0.43 CON
nickel	0.038	0.116	NI = +0.84 + 0.22 pH + 1.91 DEP
selenium	0.106	0.144	SE = +0.015 + 9.09 ESE + 0.11 CON
sulfur	0.008	0.086	S = +1310 + 39.4 pH + 459 DEP
zinc	0.005	0.038	ZN = +13.0 - 0.03 EZN - 1.48 CON
Vicia americana			
chromium	0.144	0.374	Log(CR) = +0.71 + 0.07 pH + 0.54 Log(ECR) - 0.64 CON - 0.24 DEP
copper	0.259	0.440	Log(CU) = +1.17 - 0.03 pH + 0.54 Log(ECU) - 0.24 DEP
molybdenum	0.029	0.075	MO = +1.62 - 3.76 EMO - 0.85 CON
nickel	0.343	0.343	Log(NI) = +0.36 + 0.013 pH + 0.33 ENI
selenium	0.211	0.240	Log(SE) = +1.32 + 0.20 pH - 0.40 CON - 0.21 DEP
sulfur	0.018	0.134	S = +1930 + 145 pH + 1340 CON - 690 DEP
zinc	0.179	0.231	ZN = +65.1 - 3.91 pH + 1.04 EZN - 9.47 CON - 9.56 DEP

1/ June collection.
2/ September collection.

explained by the models, increased with the second collection for all elements. (The second collection concentrations of chromium, copper, molybdenum, nickel, and selenium increased while sulfur concentrations decreased, see Section 4.10.2.) The differences in R^2 between the two collections of Koeleria cristata indicate that molybdenum and zinc concentrations became more dependent upon soil pH and extractable soil concentrations of molybdenum and zinc, respectively, as the species aged.

5. DATA INTERPRETATION AND RESULTS

5.1 Coal

5.1.1 Element Concentrations

Additional data representing concentrations of elements in coal from the Indianhead Mine and the Dunn Center Bed in Dunn County are presented in Table 55 (31). The concentrations of elements in coal obtained by this project, shown in Table 5, are in agreement with these data.

The standard deviations of element concentrations in coal samples from Dunn County indicate that large sample-to-sample variations of concentrations occur. Similarly, the range of concentration for twelve samples taken over a one-hour period from coal entering the boiler of the study facility were shown in Table 5. Thus, the mine-to-mine variations in Table 5 may not be significant.

The true mean concentration of coal at a given location in a coal seam requires averaging concentrations from many samples. A study is needed to determine the number of samples required which will provide the mean concentrations of elements in coal.

The concentrations of elements in Tables 5 and 55 are given in units of micrograms per gram (μg/g), which is equivalent to tons of element per million tons (dry weight) of coal.

TABLE 55

ELEMENT CONCENTRATIONS (μg/g) IN COAL1/

Element	Indianhead Mine2/ mean	Dunn County Dunn Center Bed3/ mean	std/dev.
Silver, Ag	<0.1	<0.1[b]	0
Aluminum, Al	5,666[a]	6,697[c,d]	
Arsenic, As	8	10.13	5.12
Gold, Au	<0.1	<0.1[b]	0
Boron, B	56	62.95	50.38
Barium, Ba	616[b]	229.82	146.83
Beryllium, Be	0.27	0.31	0.22
Bismuth, Bi	<0.1	<0.1[b]	0
Bromine, Br	0.27	1.71	1.03
Calcium, Ca	16,225[a]	16,108[c,d]	
Cadmium, Cd	<1[b]	0.21[f]	0.14
Cerium, Ce	34.6	14.06	8.79
Chlorine, Cl	26.7	46.62	31.03
Cobalt, Co	1.2	4.98	4.88
Chromium, Cr	5.3	65.26	137.19
Cesium, Cs	4	0.26	0.29
Copper, Cu	10.6	22.92	18.01
Dysprosium, Dy	0.67	0.1[b]	0
Erbium, Er	<0.1	<0.1[b]	0
Europium, Eu	0.4	0.26	0.13
Fluorine, F	29.3[c]	20.83[g]	6.38
Iron, Fe	7,936[a]	7,216[c,d]	
Gallium, Ga	5.3	4.58	2.41

TABLE 55 continued

ELEMENT CONCENTRATIONS (μg/g) IN COAL[1]

Element	Indianhead Mine[2] mean	Dunn County Dunn Center Bed[3] mean	std/dev.
Gadolinium, Gd	0.8	0.23	0.17
Germanium, Ge	0.27	0.60	0.81
Hafnium, Hf	<0.1	<0.1[b]	0
Mercury, Hg	0.2[d]	0.20[i]	0.13
Holmium, Ho	0.4	0.1[b]	0
Iodine, I	0.13	0.39	0.24
Iridium, Ir	<0.1	<0.1[b]	0
Potassium, K	268[a]	462[c,d]	
Lanthanum, La	16	5.83	3.91
Lithium, Li	0.67	1.24	1.57
Lutetium, Lu	<0.1	<0.1[b]	0
Magnesium, Mg	3,877[a]	5,039[c,d]	
Manganese, Mn	70.7	248.90	177.56
Molybdenum, Mo	4	22.22	17.16
Sodium, Na	6,994[a]	2,395[c,d]	
Niobium, Nb	4	3.86	3.32
Neodymium, Nd	2.7	0.96	0.39
Nickel, Ni	6.7	11.55	8.2
Osmium, Os	<0.1	<0.1[b]	0
Phosphorus, P	236[a]	131[c,d]	
Lead, Pb	2.7	5.44	6.05
Palladium, Pd	<0.1	<0.1[b]	0
Praseodymium, Pr	1.3	0.85	0.49

TABLE 55 continued

ELEMENT CONCENTRATIONS (μg/g) IN COAL1/

Element	Indianhead Mine2/ mean	Dunn County Dunn Center Bed3/ mean	std/dev.
Platinum, Pt	<0.1	<0.1[b]	0
Rubidium, Rb	6.7	4.13	3.63
Rhenium, Re	<0.1	<0.1[b]	0
Rhodium, Rh	<0.1	<0.1[b]	0
Ruthenium, Ru	<0.1	<0.1[b]	0
Sulfur, S	11,956[a]	13,000[j]	
Antimony, Sb	0.27	0.31	0.25
Scandium, Sc	8	7.98	3.39
Selenium, Se	0.4	0.85	0.76
Silicon, Si	9,114[a]	11,011[c,d]	
Samarium, Sm	1.07	0.47	0.25
Tin, Sn	0.27	5.08	5.18
Strontium, Sr	1,729[b]	1,029.27	324.79
Tantallum, Ta		0.1[b]	0
Terbium, Tb	0.67	0.15	0.08
Tellurium, Te	0.27	0.1[b]	0
Thorium, Th	4	3.64	2.36
Titanium, Ti	193[a]	301[c,d]	
Thallium, Tl	<0.1	<0.1[b]	0
Thulium, Tm	<0.1	<0.1[b]	0
Uranium, U	4	3.15	1.79
Vanadium, V	21.3	21.93	15.46
Tungsten, W	<0.1	0.58	0.82

TABLE 55 continued

ELEMENT CONCENTRATIONS ($\mu g/g$) IN COAL[1]

Element	Indianhead Mine[2] mean	Dunn County Dunn Center Bed[3] mean	std/dev.
Yttrium, Y	13.3	23.11	16.89
Ytterbium, Yb	<0.1	0.1	0
Zinc, Zn	6.7	10.87	9.03
Zirconium, Zr	85.3	68.42	48.82

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[1] Table taken from (31).

[2] Footnotes for concentration of coal from Indianhead Mine.

a Sondreal, E. A., Wayne R. Kube, James L. Elder, "Analysis of the Northern Great Plains Province Lignites and Their Ash: A Study of Variability," U. S. Dept. of Interior, Bureau of Mines, RI 7158, 1968, analytical data taken from Tables 3 and 4, p. 8, average of 22 samples from Indianhead Mine, Mercer County, N.D.

b Method of analysis, atomic absorption vs. aqueous standards.

c Method of analysis, U.S.G.S. method, ion-selective electrode.

d Method of analysis, flameless atomic absorption (double gold amalgamation).

[3] Footnotes for analysis of Dunn Center Coal Bed, average based on 12 samples. Method of analysis, spark source mass spectrometer unless otherwise noted.

b Detection limit used 0.1 ppm.

c Method of analysis, ASTM, D 2795-69, Mineral Analysis of Coal and Coke Ash, part 19, 1974.

d Average of four lowerbed composites, Nos. 3, 4, 5, 6, Report of Paul Weir Co. to Natural Pipeline Co. of America, October 27, 1972.

f Method of analysis, atomic absorption vs. aqueous standards.

g Method of analysis, USGS method, ion-selective electrode.

h A coal sample run by neutron activation showed 0.47 ppm, it was not used in average.

TABLE 55 concluded

[i] Method of analysis, flameless atomic absorption (double gold amalgamation).

[j] Method of analysis, ASTM, D 271-68, Laboratory Sampling and Analysis of Coal and Coke, part 19, 1969.

[l] A coal sample run by neutron activation showed .069 ppm, it was not used in average.

[m] A coal sample run by neutron activation showed 1.03 ppm, it was not used in average.

[n] A coal sample run by neutron activation showed .545 ppm, it was not used in average.

Therefore, the data also express the amounts of elements in tons which are contained within one million tons (dry weight) of coal consumed by a coal-fired facility.

5.1.2 Coal Versus Soil Element Concentrations

Concentrations of selected elements in coal and in crustal surface (soil) are compared in Table 56. With the exception of calcium, molybdenum, and sulfur, the soil concentrations are greater than the coal concentrations. Greater soil concentration versus coal concentrations have previously been reported for western North Dakota (31); however, this observation is reverse of comparisons for some eastern coals.

5.2 Fly Ash

5.2.1 Particle Size Dependent Element Concetrations

Measurement of concentrations of elements in stack fly ash have demonstrated that the concentrations of certain elements become greater for particle sizes less than about 3 micrometers (8, 32, 33, 34, 35). This phenomenon has been attributed to the higher volatility of these elements at the combustion temperatures of the boilers with subsequent condensation on surfaces of smaller ash particles (32, 33). The potential size dependent concentrations have been shown to vary with coal source (36) or emission control systems (37, 38).

TABLE 56

COMPARISON OF COAL AND SOIL ELEMENT CONCENTRATIONS (μg/g)

Element	Coal Concentration Baukol-Noonan Cener Mine	Crustal Concentration 10-cm Samples
Aluminum	8,300	53,760
Calcium	16,225	12,000
Cadmium	1[1]	1
Chromium	5.3[1]	49.0
Copper	6.1	18.8
Iron	6,900	22,880
Potassium	3,800	16,700
Magnesium	3,877	6,810
Manganese	40	471
Molybdenum	4	3
Sodium	4,000	10,550
Nickel	6.9	25.8
Lead	2.7[1]	14.6
Sulfur	8,500	332
Selenium	0.4[1]	0.56
Titanium	380	2,960
Zinc	8.0	74

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[1] From (33), shown in Table 55.

Particle size dependent element concentrations are suggested for certain elements by the data shown in Tables 8 and 9. However the size dependence implied is not supported by other research in the literature. For example, zinc concentrations in Tables 8 and 9 increase with increasing particle size.

The concentrations of some elements for the various fly ash size fractions in Tables 8 and 9 are larger than concentrations reported by other investigators (38) but are similar to other studies (33).

5.2.2 Emission Rates

The fraction of elements entering the boiler with coal which is discharged in flue gas has been determined for three facilities having different boiler and emission control configurations, Table 57 (7). The fractions obtained for this project (Tables 11 and 12) are as much as a factor of 10 lower for all elements, except arsenic, copper, and lead.

From Table 57, it is evident that less than 5 percent of the mass of elements in feed coal escapes in the flue gas waste streams (exceptions are chlorine, mercury, molybdenum, and arsenic) of power plants equipped with precipitators or scrubbers. Thus, greater than 95 percent of the mass of these elements is trapped within the power plant and does not become available for atmospheric dispersion.

TABLE 57

FRACTION OF ELEMENTS ENTERING WITH COAL DISCHARGED IN FLUE GAS FOR SAMPLED STATIONS1/

Element	Station I Flue Gas Scrubber	Station II Flue Gas Hotside Precipitator	Station III Flue Gas Cyclone
Aluminum	0.25	0.7	11.2
Antimony	0.61	3.9	77.9
Arsenic	7.5	0.05	20.5
Barium	<0.84	<0.09	<1.6
Beryllium	0.65	2.0	6.5
Boron	5.9	4.7	54.1
Cadmium	7.0	3.8	41.1
Calcium	0.85	0.8	16.6
Chlorine	75.0	80.2	80.0
Chromium	9.9	12.4	40.3
Cobalt	2.6	1.5	28.5
Copper	0.66	0.8	28.9
Fluorine	2.0	7.6	74.0
Iron	0.63	0.8	17.5
Lead	1.9	7.5	64.6
Magnesium	1.2	0.8	14.8
Manganese	0.38	1.2	12.5
Mercury	86.8	97.9	96.1
Molybdenum	43.2	9.4	63.0
Nickel	4.1	18.2	62.8
Selenium	2.2	27.7	65.4
Silver	4.7	1.3	< 15.9
Sulfur	62.2	87.8	98.1
Titanium	0.30	0.6	7.9
Uranium	2.0	1.5	27.6
Vanadium	2.5	2.4	24.9
Zinc	2.5	2.6	52.7

1/ From (7).

5.2.3 Influence of Facility Configuration

The data shown in Table 57 clearly indicate that the fraction of elements in coal contained in the flue gas waste stream varies widely among facility design. The study facility emission control system for Unit II is a hotside electrostatic precipitator followed by a wet scrubber.

Perhaps the lower emission fractions of the study facility (Tables 11 and 12) for most elements were due to this combination of equipment. Perhaps lignite coal, having a larger water content, will provide different particle size dependent concentrations when boiler products are quenched in an appropriate air waste emission system.

5.3 ATDM Model

5.3.1 Influence of Extra Area Sources

The four sources adjacent to the study area are not sufficiently removed form the study area to avoid significant affects relative to the study facility.

The seasonal ground-level air concentrations of zinc contributed to aerosol by the plumes of the four sources and the plume of the study facility are of the same order of magnitude in the northwest quadrant of the study area, see Figures 23 and 25. The difference between the two patterns is slightly greater southwest of the study facility where the plume increments of ground-level air concetrations are about a factor of two greater for the study facility than for the four adjacent facilities.

In the northwest quadrant of the study area, the annual average rate of deposition from the plumes of the four facilities adjacent to the study area is also of the same magnitude as the rate of deposition from the study facility, see Figures 26 and 27. Similarly, the rate of deposition in the southeast quadrant from the study facility exceeds the rate of deposition from the four adjacent facilities by a factor of almost two.

The implication of this analysis is that the study area was not isolated from other coal-fired facilities. Thus, the computer modeling analysis indicates that a criteria of study area selection (Section 2.1) was not satisfied.

5.3.2 ATDM Relative to Aerosol and Soil

The fraction of additional zinc in aerosol from the plume of the study facility suggests the potential impact. This fraction was determined as follows:

> Assumed concentration of zinc in air from plume of study facility at 20 picograms per cubic meter (Figure 23).
>
> Assumed suspended particulate loading of 20 micrograms per cubic meter (39).

Assumed zinc concentration in aerosol (Table 17) of 0.0003 micrograms per microgram of aerosol.

The resulting fraction of zinc in aerosol from the study facility, as projected by the computer model, is 0.33 percent.

The annual deposition relative to surface soil concentrations (measured in 1978) also suggests the potential impact of the study facility. The rate was determined with the following data.

Assumed an annual average deposition rate of 1.0 picogram per square meter per second (Figure 24).

Assumed a soil volume of surface area equal to 1 square centimeter and 1.3 centimeters deep.

Assumed a soil bulk density of 1.4 grams per cubic centimeter.

The rate of deposition reduces to 0.0017 micrograms per gram of soil per year. The average total concentration of zinc in the surface soil was 83 micrograms per gram (Table 40). The concentrations of zinc in the 1.3-cm surface layer of soil becomes greater at a rate of 0.0020 percent per year (1978 base).

This comparison of computer model predictions of ground-level air concentrations of zinc contributed to aerosol and of annual deposition of zinc contributed to surface soil indicates that the study facility will not impact the study area during the short term period of one year. Extrapolation of the annual deposition to an anticipated life-span of the study facility of 40 years also indicates an insignificant affect.

5.3.3 Regression Analysis

The computer model was used as a tool for grouping all soil and vegetation plots in one data set. Since plot exposure to plumes varies due to directionally dependent atmospheric parameters, the model can project variations in the plot exposure. This was accomplished by the exposure factors for ground-level air concentration and deposition.

The additional variance explained by the exposure factors as predictors in regression models for *Andropogon scoparius* varied from 12 to 47 percent. Further, all coefficients of CON and DEP terms were positive for all elements, see Table 54. This result implies that the species was responding to environmental enrichment of the elements by the power plant plumes. However, only copper, molybdenum, and zinc are known to be required for vegetation metabolic processes.

For the remaining species, the additional variance of elemental concentrations in vegetation explained by the exposure factor predictors (CON and DEP) varied from 0 to 24 percent. However, the signs of coefficients for CON and DEP are often negative.

(Positive coefficients suggest that elemental concentrations in vegetation become larger or smaller as CON or DEP also become larger or smaller, respectively.) Since negative signs for CON and DEP should not be interpreted to mean that concentrations of elements in vegetation decrease when ground level air concentration or deposition increase, the analysis did not provide evidence of vegetation enrichment of elements for these species.

Of the elements studied, only copper, molybdenum, sulfur, and zinc are known to be required by vegetation. Therefore, it cannot be concluded that element concentrations in the species Andropogon scoparius were increased by power plant emissions of elements. The result obtained should be investigated with collection of an independent set of data including a full scope of elements and all soil parameters known to affect element concentrations.

Regression analysis of the form used for this project will likely continue to produce poor correlations between predicted and observed values of element concentrations in vegetation, until the nutritional functions and relationships of elements are better understood. It is not disconcerting to observe both negative and positive coefficients for CON and DEP predictors, because concentrations of some elements are interdependent on concentrations of other elements either directly or indirectly. This interdependence must be included in regression models. However, collecting a data set from which models can be developed will be difficult, because such a data set should be obtained from field samples as elements concentrate at different levels in vegetation in a controlled laboratory.

5.4 Aerosol

5.4.1 Multiple-Source Influence on Aerosol Concentrations

Aerosol samples were stratified by wind direction and the enrichment of element concentrations determined, Section 4.4.5. Outside sources which may influence the data are the coal-fired power plants at Beulah, Mandan, and Stanton. The Beulah facility sites A1 and A4, the study facility at Center, sites A2 and A3, and the Mandan facility are located along a straight line. Thus, sites A1 and A4, when upstream of the study facility, are downstream of the Beulah facility. Likewise, sites A2 and A3, when upstream of the study facility, are downstream of the Mandan facility.

The primary wind direction on crosswind sampling days was from the southwest. A coal-fired plant which produces charcoal briquettes is located about 110 kilometers west-southwest of the study area.

It can reasonably be assumed that any influence on enrichment factors by stack plumes and activities of the Beulah and Mandan facilities would be lesser due to their greater distances (providing greater diffusion) from the sampling sites, see

Section 4.3. Therefore, the enrichment factors for crosswind, upstream, and downstream wind conditions at the four sampling sites have been combined as given in Table 58.

The enrichment factors shown in Table 58 indicate that certain elements are enriched in aerosols relative to soil concentrations. These elements are arsenic, barium, calcium, cadmium, chlorine, copper, nickel, lead, sulfur, selenium, and zinc. However, the analysis was not able to identify a dependency of aerosol enrichment on wind direction.

This analysis failed to identify the study facility as a primary cause for enrichment of elements in the aerosol samples collected. In fact, the data of Table 58 suggest that transport of an enriched aerosol into the study area is occurring.

5.4.2 Enrichment Factors for Other Areas

Enrichment of elements in aerosols has been studied by other investigators (20, 40). Aerosol elemental enrichment factors from the Walker Branch Watershed, Tennessee, which is influenced by the deposition of elements from coal burned at the Allen Steam Plant, have been determined (41). Enrichment factors were computed for elements in Boston-Area aerosol (21). The enrichment factors for elements derived in these studies are presented in Table 59. However, both of these studies failed to conclusively demonstrate that the large enrichment factors for certain elements were caused by emissions from nearby coal-fired burners.

TABLE 58

AEROSOL ELEMENT ENRICHMENT FACTORS FOR ALL SITES

	Crosswind	Upstream	Downstream
Number of Samples	20	28	19
Element	mean/std-dev	mean/std-dev	mean/std-dev
Aluminum	1.0/0.0	1.0/0.0	1.0/0.0
Arsenic	16.3/19.1	17.1/12.9	20.1/19.2
Barium	6.8/3.5	6.6/5.7	5.2/3.6
Bromine			
Calcium	5.8/2.0	5.4/1.8	6.0/2.8
Cadmium	829/693	621/548	793/824
Chlorine	15.8/10.6	16.6/13.4	17.7/19.1
Chromium	2.1/2.6	1.7/1.2	1.9/2.4
Copper	4.5/2.9	3.7/3.1	3.8/2.7
Iron	1.8/0.63	1.6/0.39	1.8/0.75
Potassium	1.2/0.35	1.1/0.21	1.1/0.44
Magnesium	2.4/0.71	2.2/0 49	2.6/1.7
Manganese	2.0/0.68	1.9/0.37	2.3/1.0
Sodium	0.89/0.57	0.84/0.37	0.76/0.47
Nickel	5.0/7.4	4.6/5.4	4.8/6.9
Lead	101/50	99/73	93/52
Sulfur	166/121	163/121	153/120
Selenium	637/446	693/625	739/462
Silicon	1.2/0.46	1.1/0.22	1.3/0.50
Titanium	1.0/0.39	1.0/0.27	1.1/0.45
Vanadium	1.4/0.21	1.6/0.94	1.5/0.41
Zinc	6.8/6.0	4.7/3.0	4.7/3.4

TABLE 59

ENRICHMENT FACTORS OF ELEMENTS IN AEROSOLS FROM WALKER BRANCH WATERSHED, TENNESSEE, AND BOSTON-AREA

	Walker Branch Watershed1/	Boston-Area2/
Aluminum	1.9	1.0
Arsenic	35.2	---
Calcium	4.2	---
Cadmium	402	1,000
Cesium	1.0	1.9
Chlorine	295	90
Chromium	2.0	4.7
Copper	13.7	---
Iron	1.2	2.0
Potassium	1.6	---
Manganese	1.8	2.1
Nickel	---	100
Sodium	3.7	2.9
Lead	485	5,800
Sulfur	4.8	---
Selenium	380	780
Titanium	2.7	0.4
Vanadium	8.1	500
Zinc	7.2	210

1/ From (41). A rural atmosphere.
2/ From (21). An urban atmosphere.

The enrichment factors for aerosols in this project, Table 58, are similar to those in the Walker Branch Watershed. Large enrichment factors for arsenic, bromine, copper, lead, nickel, selenium, and zinc can be attributed to emissions from coal-fired burners (40, 41).

5.4.3 Size Characteristics

The concentrations, expressed as mass per unit mass, of certain elements in fly ash have been shown to become larger with smaller particle sizes (32, 33, 38). Those elements, which have particle size dependent concentrations are arsenic, cadmium, chromium, copper, nickel, selenium, lead, manganese, and zinc. Larger concentrations occur for particles less than about 3 micrometers diameter.

Particle coagulation and chemical transformation can occur in the plume between the study facility and the aerosol samplers (42). However, the effect of coagulation on particle sizes at the samplers can be assumed to be negligible to the short transport distance (time) between the stack and the samplers.

Enrichment factors (EF) for fine and coarse filters of the stacked filter unit were shown in Table 22. Those elements for which the fine filter EF exceeded the coarse filter EF were arsenic, barium, cadmium, chromium, copper, nicle, lead, sulfur, selenium, and zinc. Thus, in recognition of fly ash particle size dependent concentrations of elements, the aerosol data in

Table 22 suggest that the aerosol samplers were influenced by one or more coal burning sources.

5.4.4 Other Factors Affecting Aerosol Concentrations

Weather conditions such as temperature, humidity, precipitation, and wind speed affect suspended particulate loading and aerosol concentrations of elements in a complex process (20, 43). However, seasonal variability seems to be stronger than day-to-day variability of the effect.

The literature search activity did not produce any evidence that particle fractionation at the soil surface and subsequent particle suspension in air causes preferential enrichment of certain elements in smaller particles.

5.4.5 Evidence of Element Enrichment in Aerosol

The analysis of elemental concentrations in aerosol was unable to isolate the study facility as a contributing source to the enrichment of certain elements. These elements are arsenic, cadmium, chromium, copper, nickel, lead, sulfur, selenium, and zinc. On the basis of other research investigations, the enrichment of these elements in aerosol suggests that coal-fired sources are affecting the balance of elemental concentrations in air over the study area.

5.5 Snow

5.5.1 Mechanism for Snow Enrichment

The concentrations of certain trace elements of particles contained in stack air emissions are dependent upon particle size. Further the nucleation of atmospheric water vapor by liquid and solid water particles is well documented (44). However, the nucleation behavior of stack gas particles has not been adequately investigated.

Certain atmospheric particles act as ice nuclei which are centers (embryos) for collecting water vapor to grow ice crystals. A study of the ice nucleus concentrations in plumes downstream of two coal-fired power plants indicated that the maximum ice nucleus concentration measured in the plume was 0.3 per liter of air at -16 C. This concentration was marginally greater than the background concentration in air adjacent to the plumes (45).

Therefore, it appears more probable that any deposition of trace elements contained in plumes of coal-fired power plants would occur by washout; that is, snow crytals, while falling earthward, collect the plume gas molecules or particles. Additional research is necessary to improve the understanding of stack particles interacting with precipitation processes.

5.5.2 Evidence of Element Enrichment in Snow

Seven anions and cations were measured in snowfall. Crosswind and downstream patterns of snow concentrations for mercury and arsenic suggest, but do not conclusively indicate, that snow concentrations of these cations were larger in the plume of the study facility.

5.6 Aquatics

5.6.1 Temperature

Temperature governs physiological functions in organisms and, acting directly or indirectly in combination with other water quality constituents, it affects aquatic life with each change. These effects include chemical reaction rates, enzymatic functions, molecular movements, and molecular exchanges between membranes within and between the physiological systems and organs of an animal. Depending on the extent of environmental temperature change, organisms can be activated, depressed, restricted, or killed (46).

The Milton R. Young Power Plant cycles approximately 72 million liters of cooling water per hour. At this rate, the entire volume of Nelson Lake is cycled through the power plant about every six days.

The mean weekly surface water temperature for May-September in Nelson Lake for 1978 was 30.6 C with a corresponding mean bottom temperature of 27.3 C. The weekly averge for the upstream-downstream sites was 20 C.

Elevated temperatures are known to increase the toxic effects of poisons. It might be said that, in general, water toxicants and elevated temperatures act synergistically to produce a greater effect (46).

In fish, the sensitivity to temperature change depends on such considerations as species, age, acclimation, time of the year, and physiological state (46).

5.6.2 pH

The pH curve (Figure 34) illustrates a typical seasonal pattern, being higher in the summer than in the spring. All sites were basic throughout the growing season with several lake sites dropping below pH 7 in the spring.

The toxicity of many compounds is affected by the degree of dissociation of weak acids or bases. This dissociation is controlled by changes in pH.

A review of the effects of pH on freshwater fish has been published by the the European Inland Fisheries Advisory Commission (47). The Commission concluded: "There is no definite pH range within which a fishery is unharmed and outside which it is damaged, but rather, there is a gradual deterioration as the pH values are further removed from the normal range. The pH range which is not directly lethal to fish is 5 - 9; however, the toxicity of several common pollutants is markedly affected by pH changes within this range, and increasing acidity or alkalinity may make these poisons more toxic. Also, an acid discharge may liberate sufficient CO_2 from bicarbonate in the water either to be directly toxic, or to cause the pH range 5 - 6 to become lethal."

5.6.3 Dissolved Oxygen

Dissolved oxygen is a water quality constituent that, in appropriate concentrations, is essential, not only to keep organisms living, but also to sustain species reproduction, vigor, and the development of populations.

Temperature, partial pressure of gas, and concentration of dissolved salts are factors affecting the amount of dissolved oxygen in water.

Organisms undergo stress at reduced dissolved oxygen concentrations that make them less competitive to sustain their species within the aquatic environment. For example, dissolved oxygen concentrations around 3 milligrams per liter or less have been shown (46):

1) to interfere with fish populations through delayed hatching of eggs;

2) to reduce size and vigor of embryos;

3) to produce monstrosities in young;

4) to interfere with food digestion and acceleration of blood clotting;

5) to decrease the tolerence to certain toxicants;

6) to reduce food efficiency and growth rate; and,

7) to reduce maximum swimming speed.

It is therefore recommended that dissolved oxygen concentrations be above 5 milligrams per liter.

Both sites 1 and 2 had stream flow hampered by beaver dams; however, as dissolved oxygen concentrations illustrate (Figure 35) water at site 2 became quite stagnant by the end of July. The remaining sites averaged about 6.8 milligrams per liter of dissolved oxygen throughout the sampling period in 1978.

5.6.4 Specific Conductance - Salinity

The salinity of fresh water is defined as the total concentration of the ionic components (all of the cations and anions in solution). A measure of the total amount of ionized material in water can be obtained through determination of the electrical conductance of the solution. This is commonly called specific conductance or conductivity. In general, the range of specific conductance of natural waters should approximate that of the total dissolved solids (TDS).

The level of Nelson Lake dropped approximately one meter during the 1978 sampling period. This drop in lake level, with its corresponding rise in TDS, is dramatically illustrated by the conductivity curves (Figure 37).

Conductivity in the lake sites became larger, from about 500 microohms per centimeter in May to approximately 1200 in September. During April of 1979, conductivity at the lake sites reached a high of over 1600 microohms per centimeter, these sites remained at or near this level until the end of April at which time the lake rose over one meter due to the spring snow melt, the conductivity then dropped back to the 500 readings.

Conductivity for the stream sites throughout 1978 remained fairly constant at about 1200 microohms per centimeter, these sites usually carry a heavy load of suspended solids. The dilution effect due to the spring snow melt is illustrated in the April 1978 sampling in that conductivity dropped from 700 microohms per centimeter to 240.

5.6.5 Alkalinity

Alkalinity refers to the capability of water to neutralize acids. The presence of carbonates, bicarbonates, and hydroxides of calcium, magnesium, and sodium metals are the most common causes of alkalinity in natural waters. Components of alkalinity such as carbonate and bicarbonate will complex some toxic heavy metals and reduce their toxicity markedly.

Figure 36 presents an almost identical trend for the concentration of alkalinity with that of conductivity.

5.6.6 Trace Element Concentrations

The concentration of trace elements obtained in this study are related to three references (Table 60).

A) Safe Drinking Water Act

B) Quality Criteria for Water - US-EPA-1976

C) Water Quality Criteria as listed under the Clean Water Act

TABLE 60

WATER QUALITY CRITERIA

	Reference A [1]	Reference B - Lowest Recommended Water Quality Criterion [2]			Reference C [3]
Element	Maximum Contamination Level (μg/l)	Absolute Level	Relative Level [4]	For Protection of - Example	Criteria Summary
Arsenic	50	50		Domestic Water Supply - health	57 μg/l as a 24 average and the concentration should never exceed 130 μg/l at any time
Cadmium	10	0.4		Freshwater aquatic life - salmonoids, cladocoraus, soft water	e(0.87 ln(hardness) - 4.38) as a 24 hour average and the concentration should not exceed e(1.30 ln (hardness) - 3.92) at any time.
Chromium	50	50		Domestic Water Supply - Health	Trivalent Cr e(0.83) ln(hardness + 2.94) as a 24-hour average, and the concentration should not exceed e(0.83 ln(hardness) + 3.72). Hexavalent Cr 10 μg/l as a 24-hour average concentration and the concentration should not exceed 110 μg/l at any time.
Copper			0.1x96-hr LC50 2-3 μg/l	Freshwater aquatic life - Rainbow trout, Chinook salmon	e(0.65 ln(hardness) - 1.94) as a 24-hour average, and the concentration should not exceed e(0.88 ln (hardness) - 1.03) at any time.
Lead	50		0.1x96-hr LC50 1-5 μg/l	Freshwater resident species - sticklebacks, Coho salmon	e(1.51 ln(hardness) - 3.37) as a 24 hour average and the concentration should not exceed e(1.51 ln (hardness) - 1.39) at any time
Mercury	2	0.05		Freshwater aquatic life - to protect human consumers	The data base for freshwater aquatic life and inorganic Hg is insufficient to allow use of the Guidelines.
Molybdenum [5]					
Nickel			0.1x96-hr LC50	Freshwater aquatic life -	e(1.01 ln(hardness) - 1.02) as a 24-hour average and the concentration should not exceed e(0.47 ln (hardness) + 4.19) at any time.
Selenium	10	10		Domestic Water Supply - Health	For selenium the criterion is derived using procedures other than the guidelines, is 9.7 μg/l as a 24-hour average and the concentration should never exceed 22 μg/l at any time.
Zinc			0.1x96-hr LC50 1 μg/l	Freshwater aquatic life - Rainbow trout	e(0.67 ln(hardness) + 0.67) as a 24-hour average and the concentration should not exceed e(0.64 ln (hardness) + 2.46) at any time.

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[1] Safe Drinking Water Act.
[2] Quality Criteria for Water - US-EPA-1976.
[3] Clean Water Act - Water Quality Criteria.
[4] Often the criterion is expressed in relative terms, such as 0.01 times the 96-hr lethal concentration for 50% of the fish present (written LC50) based on a sensitive species. In these cases, examples of sensitive species are given and the criteria calculated based on the 96-hr LC50.
[5] Molybdenum is not included in either of the three references.

Reference B and C relate criteria for only freshwater aquatic life.

A water quality criteria is not a water quality standard and, in itself, has no regulatory effect. A criterion is a scientific entity, based soley on data and scientific judgement. It does not reflect consideration of economic or technological feasibility. A criterion based on the protection and propagation of fish, shellfish and wildlife, for example, is simply the best estimate informed scientists are able to make of the maximum concentration of a given pollutant that can be tolerated while still maintaining protection of aquatic ecosystems. The natural variability within the aquatic ecosystem can never be identified with a single numerical value.

In regard to reference C on Table 60, the concentrations for cadmium, chromium, copper, nickel, selenium, lead, and zinc are based on equations in which the hardness of the water is the determining component which sets the concentration of the above-mentioned elements.

Water hardness was not one of the parameters determined in this study. However, hardness values for sites 1 and 2 were obtained from the U.S.G.S., and values for sites 8 and 9 were obtained from Minnkota Power Cooperative.

From these four sites, of which sites 1 and 2 are stream sites, and sites 8 and 9 are considered as lake sites, the water hardness of the streams can be compared to the lake.

In Tables 61 and 62, the 24-hour average concentration and the concentration that should not be exceeded any time are given. These concentrations are derived from the formulas found in reference C, Table 60. The information presented in Tables 61 and 62 is for reference purposes only, and no real use can be made of the calculated maximum safe 24-hour concentrations, since 24-hour averages were not determined.

ARSENIC:

Arsenic is a naturally occurring element often referred to as a metal, although it is chemically classified as a metalloid. Arsenical compounds are found in all living organisms including those in aquatic systems. Arsenic and its compounds are used in the manufacturing of glass, cloth, and electrical semiconductors, as fungicides and wood preservatives, as well as in veterinary applications (48). The United States consumes half the world's production of arsenic, or about 37,500 tons per year, and produces about 18,000 tons per yer itself. The principle emission source for arsenic in the United States is thought to be coal-fired power plants, which emit approximately 3,000 tons of arsenic per year (48).

TABLE 61

CALCULATED CONCENTRATIONS (µg/l) OF CERTAIN ELEMENTS WHICH WOULD EXCEED WATER QUALITY CRITERIA - SITES 1 AND ~~X~~ 2

	Hardness1/	Cadmium 2/ / 3/	Copper 2/ / 3/	Lead 2/ / 3/	Nickel 2/ / 3/	Zinc 2/ / 3/
Site 1						
May	310	1.84/34.4	5.98/55.6	199/1440	118/979	91/460
June	320	1.89/35.8	6.10/57.2	209/1510	122/993	93/469
July	250	1.53/26.0	5.20/46.0	144/1040	95/885	79/401
August	280	1.69/30.1	5.60/50.8	170/1235	107/796	85/431
September	200	1.26/19.4	4.50/37.8	103/743	76/796	68/348
Site 2						
May	350	2.04/40.3	6.47/61.8	239/1729	134/1036	99/497
June	250	1.53/26.0	5.20/46.0	144/1040	95/885	79/401
July	260	1.58/27.4	5.34/47.6	152/1104	99/901	81/411
August	no flow					
September	no flow					

1/ Monthly mean in milligrams per liter calcium carbonate ($CaCO_3$).
2/ Twenty-four hour average concentration.
3/ Concentration at any given time.

TABLE 62

CALCULATED CONCENTRATIONS (µg/l) OF CERTAIN ELEMENTS WHICH WOULD EXCEED WATER QUALITY CRITERIA - SITES 8 AND 9

	Hardness1/	Cadmium 2/ / 3/	Copper 2/ / 3/	Lead 2/ / 3/	Nickel 2/ / 3/	Zinc 2/ / 3/
Site 8						
May	160	1.04/14.5	3.89/31	73/530	61/717	59/301
June	200	1.26/19.4	4.50/38	103/743	76/796	68/348
July	222	1.38/22.3	4.82/41	120/870	84/837	73/372
August	270	1.63/28.7	5.47/49	161/1169	103/917	83/421
Site 9						
May	168	1.08/15.5	4.02/32.4	79/571	64/734	61/311
June	200	1.26/19.4	4.50/37.8	103/743	76/796	68/348
July	222	1.38/22.3	4.82/41	120/870	84/837	73/372
August	270	1.63/28.7	5.47/49	161/1169	103/917	83/421

1/ Monthly mean in milligrams per liter calcium carbonate.
2/ Twenty-four hour average concentration.
3/ Concentration at any given time.

Analysis of 1,577 U.S. surface waters showed arsenic to be present in 87 samples, with concentrations ranging from 5 to 336 micrograms per liter as arsenic and a mean of 64 micrograms per liter as arsenic (50).

Arsenic in water is stable in four oxidation states (+5, +3, 0, and -3), depending upon chemical conditions. Arsenic as the free element (O) is rarely encountered in natural waters and has low toxicity, as it is virtual insoluble in water or in the body fluids (48). Soluble inorganic arsenate (+5) predominates under normal conditions since it is thermodynamically more stable in water than arsenite (+3) (51). Conditions of low pH, low Eh, and low dissolved oxygen in water favor the formation of lower oxidation state arsenicals such as arsenite and arsine (-3) whereas more basic, oxygenated waters result in an increase of arsenic present in the pentavalent state (51).

Both arsenate and arsenite can be removed from the water column by coprecipitation or adsorption onto iron oxides (52). Arsenate species can also be removed by adsorption onto aluminum hydroxide and calys, while arsenite is readily adsorbed onto metal sulfides (51).

Arsenic has been shown to bioconcentrate into both fresh and saltwater organisms.

In reference to the data found in Table 60, it appears that the chances of deleterious effects caused by arsenic will be remote, as arsenic concentrations were much lower than the 50 microgram per liter level.

COPPER:

Copper is an essential trace element for plants and animals. Copper occurs free in nature as natural metal, as well as in several oxide ores, carbonate and sulfide ores, the latter predominating. Copper has been mined and used in a number of products by man since prehistoric times.

Because of its outstanding qualities as a conductor of electricity, copper is widely used in the manufacture of such equipment. Copper frequently is alloyed with other metals. Compounds of copper are used for pesticides, algicides, fungicides, and as a rot-proofing agent for fabrics.

Copper has three distinctive properties that largely determine its use: toughness, high electric conductivity, and its toxicity for lower forms of life, copper (Cu) forms two series of salts, Cu (+1) and Cu (+2); both valence types form complex ions that are stable.

Over 1500 surface water samples from the United States have been examined, soluble copper was found in 74% of the samples with an average concentration of 15 micrograms per liter and a maximum concentration of 280 micrograms per liter.

Concentrations of copper found in natural waters are not known to have an adverse effect on humans.

The toxicity of copper to aquatic life is dependent on the alkalinity of the water as the copper ion is complexed by anions present, which in turn affect toxicity. At lower alkalinity, copper is generally more toxic to aquatic life. Other factors affecting toxicity include pH and organic compounds.

Actual tests show that copper sulfate in soft water (12 milligrams per liter of calcium carbonate $CaCO_3$) was toxic to rainbow trout at 60 micrograms per liter of copper. In very hard water (320 mg/l $CaCO_3$), the toxic concentration was 600 micrograms per liter of copper (53).

The copper concentration at all sites does not appear to present a problem. However, the spike that occurs in July, which shows most all lake sites going above 8 micrograms per liter with a maximum of slightly over 11 micrograms per liter, may warrant concern, if the 24-hour criteria is applied. Also, Figure 41 illustrates that copper concentrations in the lake are always greater than the stream sites. A possible explanation for this might be the influence of run-off from spoil sites of the adjacent Baukol-Noonon coal mine. It should be pointed out that ground water influence has been ruled out as a contributing factor for all of the anomallies found in the lake versus stream sites (55).

CADMIUM:

Cadmium is a silver-white metal with a low melting point and it readily dissolves in mineral acids. It is used in electroplating, paint and pigment manufacture and as a stabilizer in plastics manufacture (56). Cadmium is nonessential for plants and animals, is a common component of natural fresh waters, and can occur at extremely low concentrations (0.01 µg/l). This element is recognized to be of high toxic potential.

The determination of the significance of total cadmium concentrations with respect to possible adverse effects on aquatic life can be complicated. For example, there are a variety of possible chemical forms of cadmium in natural waters which may display different toxicity or bioaccumulation in addition to substances causing synergistic and antagonistic effects. However, in most situations sufficient cadmium can be dissolved to cause toxic effects to aquatic organisms (57). Cadmium ion is precipitated from solution by carbonate, a hydroxide, and sulfide ions (57), and forms soluble complexes with other anions (58). Hardness components, common to all natural waters, are known to act antagonistically with cadmium to reduced toxicity. Cadmium is strongly adsorbed to clays, muds, humic and organic materials and some hydrous oxides (59), all of which tend to remove it from the water column by precipitation.

Most fresh waters in the United States contain less than 1 µg/l of cadmium, although levels as high as 120 µg/l have been reported (54).

In the aquatic environment, cadmium is acutely toxic to fish at concentrations as low as 1 µg/l (60, 61). Chronic toxicity to fish has been reported at approximately the same levels (62). Water quality also effects cadmium toxicity independent of its effect on solubility. It has been shown that, in acute tests, calcium ions protect fish against cadmium toxicity (61). Cadmium has been reported to bioconcentrate in fish tissues to levels 2,000 times as great as those of ambient waters (63).

The concentration of cadmium is quite low at all sites and does not appear to present a problem.

CHROMIUM:

Chromium is found in air, soil, some foods, and most biological systems; it is recognized as an essential trace element for humans. This analysis of 1,577 surface water samples collected from 130 points in the United States showed that 386 samples contained chromium from 1 to 112 micrograms per liter; with a mean of 9.7 micrograms per liter (50).

Chromium can occur in every one of the oxidation states from -2 to +6. The trivalent form is the most stable oxidation state and is the form most commonly found in nature.

The hexavalent form of chromium appears to be much more toxic than the trivalent form; however, both are relatively nontoxic to mammals and other vertebrates (64).

Symptoms of excessive dietary intake of chromium in man are unknown, and chromium deficiency is of greater nutritional concern than over-exposure.

Chromium appears to be of little concern as the concentrations are low. The criteria, as presented in reference C, is not applicable due to the fact the speciation of chromium was not done.

MERCURY:

Mercury is widely distributed in the environment and, biologically, is a nonessential element. Mercury has three oxidation states: zero (elemental mercury); +1 (mercurous compounds); and +2 (mercuric compounds). Mercury is present in all terrestrial soil and rock. The average amount is approximately 0.05 parts per million. Certain large mercuriferous belts which occur in sediment and volcanic rock, consisting largely of cinnabar (HgS), may contain from 1 to 30 ppm. During the weathering of rocks and deposits, mercury may enter the sediment of streams and lakes (66).

Perhaps the largest quantities of mercury added to the environment by man are released with the burning of natural fuels (67).

Industrial uses of mercury are in electic apparatus and measuring devices; agricultural and industrial poisons, insecticides, fungicides, and bactericides.

The toxic effects of mercury on many forms of living organisms are well documented in literature.

Most recent concern over mercury has been focused on water pollution and the resultant contamination of fish. The degree to which the situation is man-made is still in dispute. The amount of natural mercury in streams is less than 0.1 microgram per liter (68). Waters near mercury deposits contain 5 to more than 100 micrograms per liter. It has not yet been shown what percentage of this total mercury in water is in the form of the water soluble and toxic methyl mercury. The conversion of inorganic mercury to organic by methanogenic bacteria appears to be ubiquitous. Thus, lakes contaminated by inorganic mercury may act as a continuous source for the production of methyl mercury.

Methyl mercury is concentrated in fish by approximately 5,000-fold that of the surrounding water (69) by entering through the gills during respiration or by ingestion of mercury adsorbed on phytoplankton. Once bound to protein, the half-life in fish has been judged to be two to three years, and the binding is of such strength that it is not disrupted by freezing, boiling, or frying.

With the exception of sites 4 and 9 during the first week of June, mercury concentrations are generally below the detection limit and appear to be of little concern.

MOLYBDENUM:

This silvery white metal and its salts are generally not considered to be significant water pollutants at the present time. Although the element occurs in minerals such as molybdenite (MoS_2), powellite ($CaMoO_4$), and wulfenite ($PbMoO_4$), it is not widely distributed in nature. Molybdenite (MoS_2) is the only important mineral source at present and it is commonly associated with copper ores; thus, production of molybdenum is regulated to a considerable degree by the demand for copper.

The metal and its salts are used principally for metallurgy and for electrical and electronic apparatus. It is also used in the glass and ceramic industries for the production of pigments and as a constituent of fertilizers for leguminous crops.

Man's activities contribute molybdenum to the environment in metallurgical processing, phosphate fertilization, phosphatic-detergent discharges, and in coal and oil burning.

Molybdenum is an essential trace element for plants and animals, including humans.

Molybdenum occurs in nature with valences of 4+ (in the sulfide molybdenite) and 6+ in molybdenates and possibly in the 3+ and 5+ states.

Molybdenum toxicity in livestock is well documented with cases of molybdenosis occurring in North Dakota due to emission from a uraniferous lignite ashing plant (1).

The interesting point about molybdenum is that the lake sites are always higher than the stream sites (Figure 43); however, the concentration of both lake and stream sites are quite low. One possible explanation is the mineralization of the coal dust as it is blown from the coal storage piles at the power plant into Nelson Lake.

NICKEL:

Biologically, nickel is a nonessential, nonbeneficial element seldom occurring in nature in the elemental form. Nickel compounds are found in many ores and minerals. Nickel salts are soluble and can occur as a leachate from nickel-bearing deposites (65).

Nickel is considered to be relatively non-toxic to man (65) and a limit for nickel is not included in the Safe Drinking Water Act. The toxicity of nickel to aquatic life indicates tolerances that vary widely and that are influenced by species, pH, synergistic effects and other factors (70).

Nickel concentrations do not appear to present a problem. However, the stream sites are generally higher than the lake sites, except during the spring (Figure 44). The cause of this phenomenon is unknown.

LEAD:

Lead is a soft gray, acid-soluble metal. It is used in electroplating, metallurgy, and the manufacture of construction materials, radiation protective devices, plastics and electronics equipment.

As far as is known, lead has no beneficial or desirable nutritional effects. Lead is a toxic metal that tends to accumulate in the tissues of man and other animals. The toxic effects of lead have been extensively tested on a wide variety of freshwater organisms.

The toxicity of lead in water, like that of other heavy metals, is affected by pH, hardness, organic materials, and the presence of other metals. The solubility of lead compounds in water depends heavily on pH and ranges from about 10,000,000 micrograms per liter of lead at pH 5.5 to 1 microgram per liter at pH 9.0 (71).

Inorganic lead compounds are most stable in the plus two valence states, while organolead compounds are more stable in the plus four state (71).

Lead concentrations in fresh water range from 2 to 140 micrograms per liter, with a mean of 23 micrograms per liter (59).

In the aquatic environment, lead has been reported to be acutely toxic to invertebrates at concentrations as low as 450 micrograms per liter and chronically toxic at less than 100 micrograms per liter (72).

Lead concentrations are extremely low and appear to present no problem.

SELENIUM:

The published data base on the effects of selenium on freshwater organisms is limited and there are no data on the chronic effects other than mortality to fish or invertebrate species. However, the data base on most all other aspects of selenium has reached voluminous proportions in the past decade.

Selenium is a naturally occurring element used in photocopying, the manufacture of glass, electronic devices, pigments, dyes and insecticides (73). It is also used in veterinary medicine (74) and antidandruff shampoos (75). The major source of selenium in the environment is the weathering of rocks and soils (76), but human activities contribute about 3,500 metric tons per year (77).

Biologically, selenium is an essential trace element for animals, including Man. It is nonessential for plants. Health problems associated with selenium in animals exist at both ends of the nutritional spectrum; because of both deficiency and excess. Historically, selenium has been recognized as a toxicant, associated with animal diseases referred to as "alkali disease" or "blind staggers".

Selenium is considered toxic to Man. Symptoms appear similar to those of arsenic poisoning (78).

The levels of selenium in water are generally proportional to the selenium in the soil. In low selenium areas, the content of water may be well below 1 micrograms per liter (78). In water from seleniferous areas, levels of selenium of 50 to 300 micrograms per liter have been reported (80). Selenium appears in the soil as basic ferric selenite, calcium selenate, and as elemental selenium.

Elemental selenium must be oxidized to selenite or selenate before it has appreciable solubility in water. Selenium may assume any of several valence states ranging from -2 to +6. Depending on its oxidation state, selenium may act as either an oxidizing agent or a reducing agent (81). Inorganic selenium may be converted to organic forms by biological action (81). Biological systems may also convert nonvolatile selenium compounds to volatile ones which might escape into the air (81).

In South Dakota (82), 586 samples of ground and surface waters were analyzed for selenium. It was found that over 80 percent of the element occurs as the selenate (SeO_4), the rest as selenite (SeO_3). Selenium content of 115 surface water samples from this study found ranges from 0 - 117.5 micrograms per liter with 11 samples exceeding 10 micrograms per liter.

Of the ten elements studied in the aquatic portion of this study, selenium appears to present the greatest concern. A majority of the time (Figure 46) its concentrations are in excess of all of three standards and/or criteria presented in Table 60. This is surprising because the selenium concentration in the soil from the surrounding area is quite low.

ZINC:

Zinc usually is found in nature as the sulfide; it is often associated with sulfides of other metals, especially lead, copper, cadmium, and iron.

Zinc, as the metal, is used extensively for galvanizing, alloys, for electrical purposes, in printing plates, for dye-manufacture, and for many other industrial purposes. Zinc salts are used in paint pigments, cosmetics, pharmaceutics, dyes, insecticides, and other products.

Zinc is an essential and beneficial element in plant, animal, and human metabolism. Zinc compounds are relatively nontoxic to birds and mammals (83).

The toxicity of zinc compounds to aquatic animals is modified by several environmental factors, particularly hardness, dissolved oxygen, and temperature (84).

The concentrations of zinc are also very low and, therefore, do not appear to present a problem.

5.7 Sediments

Because potentially harmful substances such as trace metals tend to accumulate in sediments, there has been much concern over the possible release of sediment-bound trace metals and the subsequent environmental effects on aquatic organisms.

The sediment portion of this study was undertaken to compliment the aquatic analysis and to provide baseline information on the concentration of nine elements. The sediments were collected during the third week in July of 1978 and subjected to the same analytical analysis as the soils.

In examining the distribution coefficients (range of 13 to 160,00), it is observed that sediments are one of the most concentrated reservoirs of trace metals in the aquatic environment.

The utilitarian value of this data is limited, as the availability to macrobiota of sediment-found metals remains virtually unknown (85).

In the aquatic ecosystem, organisms die and decay, releasing their chemical constituents into the lake or stream in either particulate or dissolved form. In addition, these organisms are consumed by other organisms.

In the case of the aquatic macrophytes, few reports involving prediction of heavy metal uptake are available (86, 87). The prediction of crop responses to available nutrients in agricultural soils has been studied at length for many years. Numerous soil extraction and testing procedures have been developed to determine the availability of nutrients for crop production. Similar techniques must be developed for nonagricultural plants, especially aquatic plants.

The intriguing data shown by the distribution coefficients clearly demonstrates the need for more detailed research into this area. Specific conductance, pH, and salinity have been shown to affect trace metal uptake by marsh plants (88). Organic matter appears to be an important factor in complexation of heavy metals in water and sediments (89). The ability of hydrous oxides of iron, manganese, and aluminum to sorb cations and anions is well established (90, 91, 92, 93).

Under oxidizing conditions, redox-sensitive hydrous oxides of iron and manganese in sediments are excellent scavengers of trace elements; however, under reducing conditions they are solubilized and may result in increases in concentrations of cations and anions in overlying waters (94, 95, 96).

The work of (97), indicates that marsh plant uptake of zinc, copper, and cadmium, and to some extent lead and chromium, from dredged material can be predicted using a DTPA extraction procedure. The same work states that the prediction of plant uptake of nickel or mercury was not possible.

After examining a number of chemical extractants to estimate the bioavailability of sediment-found trace metals, researchers concluded that it is unlikely that any single chemical extrant will adequately describe to biologically available fraction of numerous trace metals (98).

In comparing Table 37 and 39 the range of elemental concentration for the total fraction of both sediments and soils are about the same. However, when comparing the extractable fraction of the two, great differences occur, especially in the clay sediments; for example, over 15 times more extractable copper in the clay sediments than in the soils, over 6 times more lead, and over 186 times more sulfur.

The data indicates there is a potential for fairly large concentrations of cetain trace elements to become available to aquatic organisms.

5.8 Soils

5.8.1. General Discussion

Every naturally occurring element probably exists in soil, but the mere existence of any element in the soil, even in close contact with living plant roots and microorganisms, is not in itself sufficient to initiate the movement of this element into a biological cycle. The problems of soil chemistry of the elements are often centered around the solubility of the various elements with the amounts in solution at any one time making up only a small fraction of the total amount of that element present in the soil mass.

The sources of metals in the soil as outlined are as follows (99):

1) metals contained natively in rocks and minerals from which the soil was found,

2) metals added as impurities in fertilizers and lime, as constituents of pesticides and manure or as contaminants of sewage sludge,

3) metals in debris from industrial and mining wastes, fossil fuel combustion products, wind-eroded soil particles, atomic testing, pollen, sea spray, and meteoric and volcanic material which settles or rains out; and,

4) metals in soil particles displaced through water erosion or metals dissolved or suspended in the water itself.

Scientific knowledge of the chemistry of toxic metals in soils is very incomplete and largely speculative. The associations of metals in soils include those (a) in minerals as part of their regular structure and as interstitial impurities; (b) as simple and complex inorganic precipitates; (c) as simple and complex inorganic ions; (d) incorporated in organic matter and microorganisms; (e) as soluble or insoluble organic complexes or chelates; (f) adsorbed as ions on charged surfaces of clays, precipitates, and organic matter; and (g) in various complex combinations of the above associations (99).

Both total and extractable elemental concentrations for cadmium, chromium, copper, lead, molybdenum, nickel, selenium, sulfur, and zinc were determined. Total concentrations were obtained to get a "feel" for which elements could enter the labile pool. Total concentrations for aluminum, calcium, iron, potassium, magnesium, manganese, sodium, and titanium were needed to obtain a large group of elements for a Chemical Mass Balance procedure.

5.8.2 Nutrient Availability

The predominant route for the cycling of trace elements in biological systems follows from soil, to plant, to animal or man. Only a small portion of each nutrient present in soil is available to plants. Most of it is chemically locked up in the mineral and organic matter; thus it is unavailable until decomposition takes place. Such decomposition occurs slowly over a long period, and nutrients are gradually released (100).

5.8.3 Soil Organic Content and Cation-Exchange Capacity

The elements aluminum, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc occur most often as cations is the soil (100, 101). The availability of these elements is controlled in part by the cation exchange capacity (CEC) of the soil. Organic content of soils and its influence on soil properties, and consequently on plant growth, is very significant. The organic fraction has a far greater CEC, weight for weight, than the inorganic (100). Besides high CEC, organic soils do not hold some elements very strongly but have specific reactions arising from a chelating ability and a tendency of those metals to combine with the chelating groups (102).

5.8.4 pH

The most important single aspect of the reaction between elements and soil is the effect of pH. Trace elements are held far more firmly as the pH rises from 5 to 7 (102). Cations are generally bound more tightly in neutral or slightly alkaline soils.

The elements molybdenum and selenium usually occur as divalent anions in the soil solution. They are more soluble in neutral to alkaline soils (103, 104). In general, trace anions are more leachable than cations (104).

All of the soils in the study area are calcareous, with pH ranging from 6.3 to 8.6, with a mean of 7.4 for the 64 plots.

5.8.5 Element Concentrations

In comparing the soil trace element concentrations (Table 39), to the work of (103), Table 63, one finds that all of the elements are within the expected ranges.

5.8.6 Comment on Stratified Analysis

Since element concentrations in fly ash are size dependent for certain elements, it would be expected that two forms of deposition pattern behavior occur. One form for those elements which have larger concentrations with smaller fly ash particles, and another form for those elements which have consistent concentrations for all particle sizes.

If the above is true, then the distance dependent linear regression of soil concentrations would be expected to identify common relationships within the two subgroups of elements, given that other factors are equal.

Particle coagulation in the plume of small particles into agglomerates of larger particles of sufficient size to settle to the ground surface complicates the physical forces at work. Perhaps the anomoly of soil ratios, Figure 51, at about 14 kilometers downstream of the study facility is a result of particle coagulation and fallout.

5.8.7 Evidence of Element Enrichment in Soil

The statistical analysis of the elemental concentrations in soil surrounding the study facility suggested, but did not indicate, that enrichment of the soil is occurring as a result of the operation of the study facility. A summary of each analysis is given below.

1) Elemental concentrations in the 1.3-cm samples were significantly greater than concentrations in the 10-cm samples for certain elements. These elements were extractables of cadmium, chromium, copper, lead, and zinc, and totals of lead, zinc, and manganese.

2) The correlation coefficient between the ATDM deposition exposure factor and soil elemental concentrations were larger for the 1.3-cm samples versus the 10-cm samples. However, mean elemental concentrations for subgroups of soil plots stratified by the ATDM deposition exposure factor did not consistantly indicate higher

concentrations of elements for plots having larger predicted deposition.

3) Patterns of ratios of concentrations of certain elements in two surface layers of soil suggest that the concentrations of these elements change simultaneously from plot-to-plot. The patterns are not well correlated with the deposition or ground-level air concentration ATDM exposure factors.

4) Soil concentrations of elements did not significantly decrease (increase) as distance between the study facility and soil plot increased.

The increased concentrations of some elements in the 1.3-cm layer of soil may represent a transfer of these elements from the root zone to above ground portions followed by an organic complexing which limits downward mobility of the elements. Since the 10-cm samples included the 1.3-cm layer, larger differences can be expected between the 1.3-cm layer and the lower 8.7 centimeters of the 10-cm samples.

These observations justify the need to continue this type of analysis at about 3-year intervals. Considering the 30-40 year life span of a coal-fired power plant, slight accumulations of trace elements could occur. Each soil has a finite capacity to sorb cations, and perhaps, eventually, the soil will no longer be able to serve as a "sink" for deposited elements, especially in soils that are acidic, sandy, or low in organic matter.

TABLE 63

CONCENTRATIONS AND AMOUNTS OF SELECTED TRACE ELEMENTS IN VARIOUS PHASES OF ENVIRONMENT6/

Element	Concentration in geochemical reserves1/ (ppm)	Concentration in soils (total)2/ (ppm)	Concentration in plants3/ (ppm)	Critical levels in animal diets4/ (ppm)	Concentration in human blood4,5/ (µg/100 ml)
Cadmium	a: 0.2 b: 0.03-3 c: 0.00011	0.06(0.01-7)	(0.2-0.8), not required; toxic	Not required; moderate to high toxicity	4;accumulates in kidney
Chromium	a: 100 b: 0-100 c: 0.00005	100(5-3000)	(0.2-1.0), not required; moderately toxic	Required at ?; low toxicity	2
Copper	a: 55 b: 5-45 c: 0.003	20(2-100)	Required at 2-4; normal 4-15; toxicity at +20	Required at 1-10, dependent on Mo; low	100
Lead	a: 12.5 b: 5-20 c: 0.00003	10(2-200)	Not required; normal 0.1-10; toxic in culture soln.	Not required; moderate toxicity	27
Manganese	a: 1000 b: 50-1100 c: 0.002	850(100-4000)	Required; normal 15-100; toxicity depends on Fe:Mn ratio	Required at 10-40; low toxicity	3
Molybdenum	a: 1.5 b: 0.2-3 c: 0.01	2(0.2-5)	Required at <0.1; normal 1-100; low toxicity	Required at <0.1; moderate to high toxicity, dependent on Cu	2
Nickel	a: 75 b: 2-70 c: 0.0054	40(10-1000)	Not required; normal 1; toxic at +50	Not required; moderate to low toxicity	1-8
Selenium	a: 0.05 b: 0.1-1.0 c: 0.00009	0.5(0.1-2.0)	Not required; normal 0.02-2.0; higher in accumulations: toxic at 50-100	Required at 0.05-0.20; highly toxic	20
Zinc	a: 70 b: 10-100 c: 0.01	50(10-300)	Required at 8-15; toxic at +200	Required at 10-40; low toxicity	650

1/ Generalized from Bowen (1966), a = Value for igneous rocks; b = value for sedimentary rocks; c = value for seawater.

2/ Generalized from Bowen (1966).

3/ Generalized from Chapman (1966). Concentrations on dry basis.

4/ Primarily from Underwood (1962), plus various sources. High toxicity indicates dietary level of <10 ppm may be detrimental. Moderate toxicity indicates level of 10-100 ppm may be detrimental. Low toxicity means +100 ppm required for detrimental effects. All concentrations on basis of entire diet (dry). Fluorine would be classified if in water, but moderately toxic in food.

5/ From Bowen (1963).

6/ This table taken from reference (103).

5.9 Vegetation

5.9.1 Characteristics of Individual Species Studied

Agropyron smithii (Western Wheatgrass)

Western wheatgrass (Figure 15), sampled from 47 of the 64 plots, is a valuable forage grass, and one of the dominant cool-season grasses found in the study area. Leaf growth normally begins in early April and continues until mid-July.

Andropogon scoparius (Little Bluestem)

Little Bluestem (Figure 16) found on 21 of the plots is a warm-season bunchgrass. It usually begins its growth in early May and completes its growth by early to mid-August. This grass is a characteristic component of the tall-grass prairies and has a reddish tinge early in the season, which becomes darker as the season progresses. This grass is not considered an important forage species due to its apparent low palatability to livestock.

Carex eleocharis (Needleleaf Sedge)

The sedges are grass-like herbs, often found in wet soils. Needleleaf Sedge (Figure 17) is a very common sedge on the prairies and may be considered the ecological equivalent of the short grass species. Needleleaf sedge has considerable forage value and generally begins growth in early April and usually reaches mature leaf height by early to mid-June. Needleleaf sedge was found on 33 of the plots.

Koeleria cristata (Prairie June Grass)

Praire June Grass, an important early grass, is very common on the prairies (Figure 18). Forty six of the plots contained this cool-season bunchgrass which normally begins growth in early April and reaches maturity by early July. The forage value of this species is rather low, as the leaves are not very palatable.

Stipa comata (Needle-and-Thread)

Forty eight of the plots contained this important cool-season mid grass (Figure 19). Growth generally begins in early April and reaches maturity by the end of June. The grains of this grass are commonly called hay needles and usually mature in early June. This grass can be pastured before the grains mature or after they drop.

The above description is condensed from (105). For a more detailed description of these grasses, plus many additional species, readers are referred to this excellent reference.

Oxytropis lambertii: (Purple Loco)

Purple Loco is a member of the pea family, and is a very common species on the prairie (Figure 20). This species is regarded as poisonous, but less so than some others and no cases of poisoning have been reported in North Dakota. Thirty three of the plots contained this species.

Vicia americana: (Wild Vetch)

Eighteen of the plots contained this member of the pea family (Figure 21). This species has very slender stems with reddish purple flowers. This specie, along with Purple Loco, are in full bloom by mid-May.

5.9.2 Element Concentrations

Element concentrations in the various plant species must be interpreted cautiously. The problem arises as to which fraction of the element accumulated by the plant comes from the soil, and which from the air. Other associated problems are: translocation and translocation rates; some species can localize potentially toxic metals in various plant parts; low level effects of metals at the time of germination; reduced or inhibited early growth and development; age of the plant; growth cycle - annual, biennial, or perennial; type of soil; and soil moisture content.

Only those elements, which were included in the initial project design, are discussed below. Data for additional elements were included in Section 4.10 to complete the data set, since concentrations of these elements were also obtained during the laboratory analysis.

CADMIUM:

After mercury and lead, probably cadmium is considered next in importance as an environmental pollutant. Its sources are many. The environmental presence of cadmium is usually linked to that of zinc because of their geochemical relationship and imcomplete technical separation.

In plants, no toxicity has been demonstrated under natural conditions. Cadmium is a non-essential element for both plant and animal growth.

CHROMIUM:

Chromium is an non-essential element for plants, but an essential trace element for animals. However, growth stimulation in plants has been reported from the application of small amounts of chromium salts (106, 107); higher rates generally tend to be toxic (107, 108). The stimulative effects of chromium on plant growth have been interpreted as limited substitution of chromate for molybdate (109), while inhibitory effects are thought to be the results of specific interaction between chromium and phosphorus (110, 111) or iron (112, 113) in plant nutrition.

Recent interest in the element chromium stems from the elucidation of its role in human health (114), along with the finding that decline in chromium levels in human tissues is probably the result of reduced dietary intake (115).

Of the elements reported in this study, chromium is one of the more intriguing. The interest in chromium stems from comparing the data on the two samplings of Koeleria cristata (June Grass) and the single sampling of Andropogon scoparius (Little Bluestem). In comparing the chromium concentration between the two collections of June Grass, the concentration is over twelve times greater in the fall collection. The data for Little Bluestem which was collected at maturity in late August shows chromium concentrations approaching those of the September collection of June Grass. With the exception of the September collection of June Grass and Little Bluestem, the remaining species are within the expected range for chromium concentrations.

A point of interest is that an extensive review of the literature did not reveal any work which indicated that chromium accumulated in the above ground portion of the plant. To the contrary, the literature states that chromium generally appears to accumulate in plant roots and is poorly translocated to the tops (116, 117, 118, 119, 120).

After re-evaluating the procedure from sampling through analysis for possible sources of contamination or analytical error, several samples of both the June and September collection of June Grass were sent to two independent laboratories for analysis. The two laboratories were the U.S. Plant, Soil and Nutrition Laboratory, Agricultural Research Service, U.S. Department of Agriculture, Ithaca, New York; and Plant Analysis Laboratory, U.S. Geological Survey, Denver, Colorado. The results obtained showed that the data were indeed real, and not artifacts due to contamination or analytical error. Perhaps aerial deposition is occurring which did not wash off during plant preparation in the laboratory. If this was so, then high chromium values in the forbes should also occur because of greater surface area of the leaf; this was not the case.

The case that aerial deposition occurs which is incorporated into the plant could be made, but is difficult to prove.

Chromium content in the 20 microgram per gram range in plants should not have any deleterious effect on herbivores (121).

COPPER:

Copper is an essential trace element for both plants and animals. Before the turn of the century copper was regarded as a plant poison. Bordeaux mixture, which consists primarily of copper sulfate, was the first widely used fungicide. In 1931, evidence of the essentiality of copper for high plants was reported in the literature.

Using the criteria of (12), which states that copper deficiency is characterized by levels of less than 4 micrograms per gram on a dry weight basis, it appears that of the seven species on Table 46 only *Oxytropis lambertii* and *Vicia americana* have sufficient copper. The range for normal growth in most plants usually falls between 5 and 20 micrograms per gram. Copper deficiencies are much more common than copper excesses.

There are usually no definite pathological symptoms beyond those of reduced growth or yield for copper deficiency. Oats, barley, and corn are some of the field crops which are sensitive to low levels of copper (122). Copper deficiency is more common in alkaline and calcareous soils, especially sandy types.

LEAD:

Lead is biologically enriched in the upper layers of soils (123). This fact is demonstrated by comparing the data on extractable and total soil lead on both the 1.3-cm and 10-cm fraction (Table 41). In both cases, lead concentrations are about twice as high in the 1.3-cm samples. Lead is very immobile in soil. The fixation of lead is principally caused by reactions involving essentially insoluble organic materials. Precipitation by carbonate and sorption by hydrous metal oxides appear to be of secondary importance (124).

Typical lead content of many food plants and trees are in the range of 1 microgram per gram (125, 126). For this study all species were below the detection limit of the analytical methodology employed. No reports could be found in the literature which indicated definite toxicity symptoms in plants that grew in areas of natural enrichment of lead only. In highly enriched areas, lead in grass can range up to 10,000 micrograms per grams (127).

MOLYBDENUM:

Molybdenum is an essential trace element for both plants and animals. It is an essential component of several enzymes, including xanthine oxidase, aldehyde oxidase, nitrate reductase, and nitrogenase. Its physiological role appear to be more critical in plants than in animals; deficiency disease has been difficult to produce in animals on molybdenum free diets, but molybdenum is critical for plant production. A number of plant diseases, such as "whiptail" of cauliflower and "yellow spot" of citrus, are known to be due to molybdenum deficiency. Deficiency levels for plants are usually indicated by less than 0.1 micrograms per grams in their tissues (128).

Much of the scientific literature concerned with molybdenum in animal nutrition has centered around toxic or excessive levels of dietary molybdenum. Many plants will accumulate, without effects upon the plant itself; at concentrations of molybdenum that will critically interfere with copper metabolism of the animal that eats the plant, and molybdenum induced copper deficiency, or molybdenosis results. Molybdenosis occurs when the copper in forage is normal (8-10 microgarms per gram) and the molybdenum is about normal (5-6 micrograms per gram for cattle or 10-12 micrograms per gram for sheep) (129).

Cases of molybdenosis were reported in 1968 in southwestern North Dakota (1). The case in point was a farm near a plant used to ash uraniferous lignite coal.

From Table 63, one would expect no problem with molybdenum as the concentrations are within the expected range.

NICKEL:

Nickel is a non-essential element for both plant and animal. The normal nickel content of plant material, ranges from 0.1 to 5 micrograms per gram, depending on the species, maturity, morphological part sampled, and time of year (130).

SELENIUM:

Selenium is non-essential for plants, and an essential trace element for animals. Selenium is probably more noted for its toxic effects upon animals than for its essential function. The problem of selenium toxicity has been reviewed in some detail (131). It should be noted that under conditions of high selenium levels in the soil, certain plants will accumulate selenium in concentrations very toxic to grazing animals, without noticeable effects upon plant growth.

The beneficial effects of selenium in animal nutrition are of relatively recent recognition, and include the discoveries of a number of selenium responsive diseases in animals. Selenium has been shown to be involved in the prevention of a variety of nutritional deficiency diseases in animals, including liver necrosis, white muscle disease, and hair and feather loss.

Although an essential element for animals, the narrow range between deficiency and toxicity requires that selenium be considered a toxic element.

As both the selenium content of the soils in the study area and the selenium concentrations in the plants studied are quite low, problems with selenium toxicity appear to be remote. Selenium concentrations in plants is considered low at 0.1 micrograms per gram and very low at 0.05 micrograms per gram (132).

SULFUR:

The sulfur requirements of plants have been noted as similar to phosphorus. Sulfur has been known to be essential for plant growth for well over 100 year, and for nearly this long it has been known to be accumulated from the soil largely in the form of sulfate ion. Sulfur dioxide of the atmosphere is available in plants; and, upon being absorbed by leaves, it is rapidly converted to the sulfate ion. The movement of sulfur in plants is, at least primarily, in the form of sulfate ion (132). Sulfur values of normal plants are in the range of 0.23 percent (133) the values found in this study are all within this range.

ZINC:

Zinc is an essential element for both plants and animals. Zinc deficiencies in soils is a major problem; whereas, zinc toxicity in plants is rare. Zinc deficiencies in soils have existed for many years with many crops. Calcareous soils, and organic soils, are more frequently zinc deficient.

Zinc is required in plants at 8 to 15 micrograms per gram. Zinc concentrations in species sampled were within this range.

5.9.3 Evidence of Element Enrichment in Vegetation

The statistical analyses of elemental concentrations in vegetation surrounding the study facility did not provide evidence of enrichment of elements in vegetation as a result of the study facility or other facilities surrounding the study area. A summary of the analyses is given below.

1) Subgroups of vegetation plots stratified by the ATDM concentrations exposure factor did not indicate higher concentrations of elements for plots having larger ground level plume concentrations of elements.

2) Concentrations of elements in vegetation did not significantly decrease (increase) as distance between the study facility and vegetation plot increased.

3) Multiple linear regression analysis of elemental concentrations in vegetation using soil predictors generally did not provide regression models which explained significant portions (greater than 50 percent) of the variance of the element concentrations. This result was likely due to variations in availability of the element in the soil at the sampling plot.

Exposure factor predictors for ground-level air concentration and deposition, when added to the regression analysis, did not provide any evidence of element accumulation in vegetation. However, the additional variance explained by CON and DEP predictors of elemental concentrations in Andropogon scoparius increased, varying from 12 to 47 percent: the reason for this result is unknown.

6. SUMMARY

This project was conceived and conducted for the broad purpose of assessing potential affects of certain elements emitted in the stack flue gas of coal-fired electrical facilities. Other projects used similar soil and vegetation grid sampling techniques (134, 135, 136, 137, 138). However, those projects analyzed soil and vegetation data sets independently. This project atttempted to combine several additional data sets, such as stack flue gas aerosol, computer modeling, and surface water, with soil and vegetation data to arrive at an interpretation of potential affects from the emission of certain elements.

6.1 OBJECTIVE-1 Baseline Concentrations

Concentrations of certain elements were obtained for coal, aerosol, surface water, sediments, soil, and vegetation. Additional data on concentrations in snowfall and rainfall were also obtained. These data will become extremely valuable for future assessments of affects of element emissions from the stacks of the study facility.

The following statements summarize observations of the levels of concentrations of elements in each data set.

Coal: 1) Concentrations of elements in coal were consistent with previous research work. Seam-to-seam and within seam variations of concentrations of elements in coal occur: these variations cause a difficult problem for obtaining representative concentrations of elements in a given coal bed.

Aerosol: 2) Concentrations of certain elements in aerosol were greater than expected by comparison to surface soil concentrations of elements. These elements were arsenic, cadmium, chlorine, copper, nickel, lead, sulfur, selenium, and zinc.

Snow: 3) Concentrations of mercury and arsenic appear to be greater in the stack plume downstream of the study facility. However, the data set was inadequate for assessing snow scavenging of stack waste emissions.

Aquatic: 4) Concentrations of elements in surface water were lower than established water quality criteria, except for selenium. Concentrations of copper, nickel, and molybdenum were different at upstream, lake, or downstream sampling sites. The cause(s) for these differences is (are) unknown.

Sediments:	5)	Concentrations of elements in clay sediments are larger than concentrations in surface soil indicating a potential for these elements to become available to aquatic organisms.
Soil:	6)	Concentrations of elements in soil were consistent with previous research work.
Vegetation:	7)	Seasonal variations of concentrations of elements in Koeleria cristata occur: the seasonal variations of this and other species is an important factor in using vegetation to identify the redistribution of elements.
	8)	Chromium accumulation occurred in Koeleria cristata: this phenomenon has not been observed by other investigators for other vegetation species.
	9)	Molybdenum and zinc concentrations in Koeleria cristata became more dependent upon soil extractable concentrations of molybdenum and zinc, respectively, and soil pH as the species aged.

6.2 OBJECTIVE-2 Air Emission Rates

The rate at which elements are emitted with the stack flue gas of a coal-fired facility becomes important in assessing the environmental redistribution of the elements, since only a small fraction of elemental mass in raw coal escapes through the system in the flue gas waste stream.

The fractional amounts of element concentrations in stack fly ash relative to feed coal were significantly less than fractional amounts reported by other investigators. A plausible explanation for this finding is likely related to the configuration of the emission control system of Unit II of the study facility.

6.3 OBJECTIVE-3 Evidence of Enrichment

Certainly, the air waste stream of a coal-fired electrical generating facility contains some mass of each element in the feed coal. The issue is whether the rates of emission of these elements are significant relative to background concentrations, and whether the additional mass of these elements becomes available to the food chain of organisms.

The data produced by this project did not provide any evidence to suggest, or indicate, that the redistribution of elements by the stack air waste stream of a coal-fired electrical generating facility causes signficant enrichment of the elements in surface water, sediments, or vegetation.

Enrichment of concentrations of certain elements in aerosol were greater relative to soil: this observation is consistent with other investigations, which suggest that it is a result of air emissions by coal-fired facilities. The analysis was unable to isolate the study facility as a source of enrichment of elements in aerosol. Four operating facilities adjacent to the project study area could have affected data collected.

The observation of enrichment of certain elements in aerosol for all wind directions may represent a general condition of the boundary layer of the atmospher~~ic~~e resulting from human activities. Global scale atmospheric motions may provide sufficient mixing of pollutants from all sources (139) to create background concentrations of some elements at enriched levels. Emissions of pollutants from local sources then would simply provide a local perturbation of an already contaminated atmosphere.

Analysis of two depths of soil samples suggested that accumulation of cadmium, chromium, copper, lead, manganese, and zinc is occurring in the surface 1.3-cm layer of soil. Additional analysis further suggested a correlation with computer model projected surface deposition, but a regression analysis indicated that soil concentrations did not change significantly with increasing distance from the study facility.

Other investigations have suggested that certain elements may be enriched in soil and vegetation surrounding specific coal-fired facilities (134, 135, 136). These results are not disputed; however, the extremely complex nature of the physical problem involved indicates that any implication of enrichment must be supported with plausible physical explanations of the redistribution and environmental transfer processes involved.

6.4 OBJECTIVE-6 Regulation

This project did not produce any justification for implementation of standards for the regulation of element emissions in air waste streams of a coal-fired facility. This project did not indicate that environmental degradation would result from redistribution of elements in coal through air to soil and vegetation surrounding the facility.

6.5 Computer Modeling

Some investigators have cited the large volumes of coal which are mined on an annual basis as cause for justifying concern over emissions of toxic elements. The comparison of projected deposition and ground-level air concentration from the study facility with soil and aerosol concentrations of elements indicates that the atmospheric diffusion of elements in the stack plume reduces the additional quantities of emitted elements to very small fractions of background soil and aerosol concentrations of these elements.

6.6 Transferability of Conclusions

The conclusions summarized above were derived from a unique ecological system involving five coal-fired facilities with individually unique affects on stack emissions of elements. These conclusions apply specifically to these unique conditions.

However, upon consideration of factors which affect concentrations of elements in air waste streams of coal-fired facilities as well as ranges of concentrations of elements in soil and vegetation (Table 63), it becomes apparent that impacts upon ecosystems by individual coal-fired facilities are minimal, at worst. In the event that large energy parks of facilities in close proximity occur, extensive monitoring and evaluation appears justified. Such is the case in western North Dakota with additional facilities currently under construction near the study area of this project.

7. RECOMMENDATIONS

The analysis and interpretation of the data collected for this project has led to the recommendations given below. Some of these recommendations apply to nearly all scientific investigations.

The entire investigation conducted under this project should be repeated. An independent set of data is necessary to substantiate the findings of this project. An independent set of data will improve the statistical odds that data were representative of the true state of environmental conditions.

The statistical methods by which data will be interpreted should be defined before field sampling is initiated. Therefore, comprehensive planning of field sampling schemes (for example, plot locations) must be based on adequate statistical approaches to interpretation of data.

The seasonal timing for sampling of vegetation is critical, since concentrations of elements can vary during the growth cycle. Sequential sampling of vegetation during the growing season is recommended.

The comparison of element concentrations in the 1.3-cm soil samples to the 10-cm soil samples appears to provide a potential method for monitoring the accumulation of certain elements. A soil sampling scheme which includes two sampling depths is recommended for projects with similar objectives.

A large base of data which includes all parameters known to affect element concentration in vegetation should be obtained for adequate modeling of soil-vegetation interactions. The predictor variables available in this project were not adequate to explain predictant (vegetation element concentrations) variance.

Changes in the "natural" balances of elements may affect plant growth and yield. Measurements of these parameters should be included in monitoring potential affects of element redistribution and accumulation.

A field investigation of the type conducted for this project requires lead time for method development and time for data compilation and interpretation. The time available for these activities on this project was inadequate for planning field sampling and for data interpretation.

Additional data on concentrations of elements in aerosol were obtained for 21 selected aerosol samples. (The laboratory analysis was funded by another funding source.) The elements were scandium, chromium, cobalt, antimony, arsenic, selenium, lanthanum, hafnium, tantalum, samarium, europium, and thorium. A computer program was developed for applying the chemical elemental balance techniques of (140). However, time resources limited preparing data for the program and analyzing the program results.

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